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ELECTROMECHANICAL

components & systems | DESIGN

NOVEMBER 1961

THE LIBRARY OF
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in this issue
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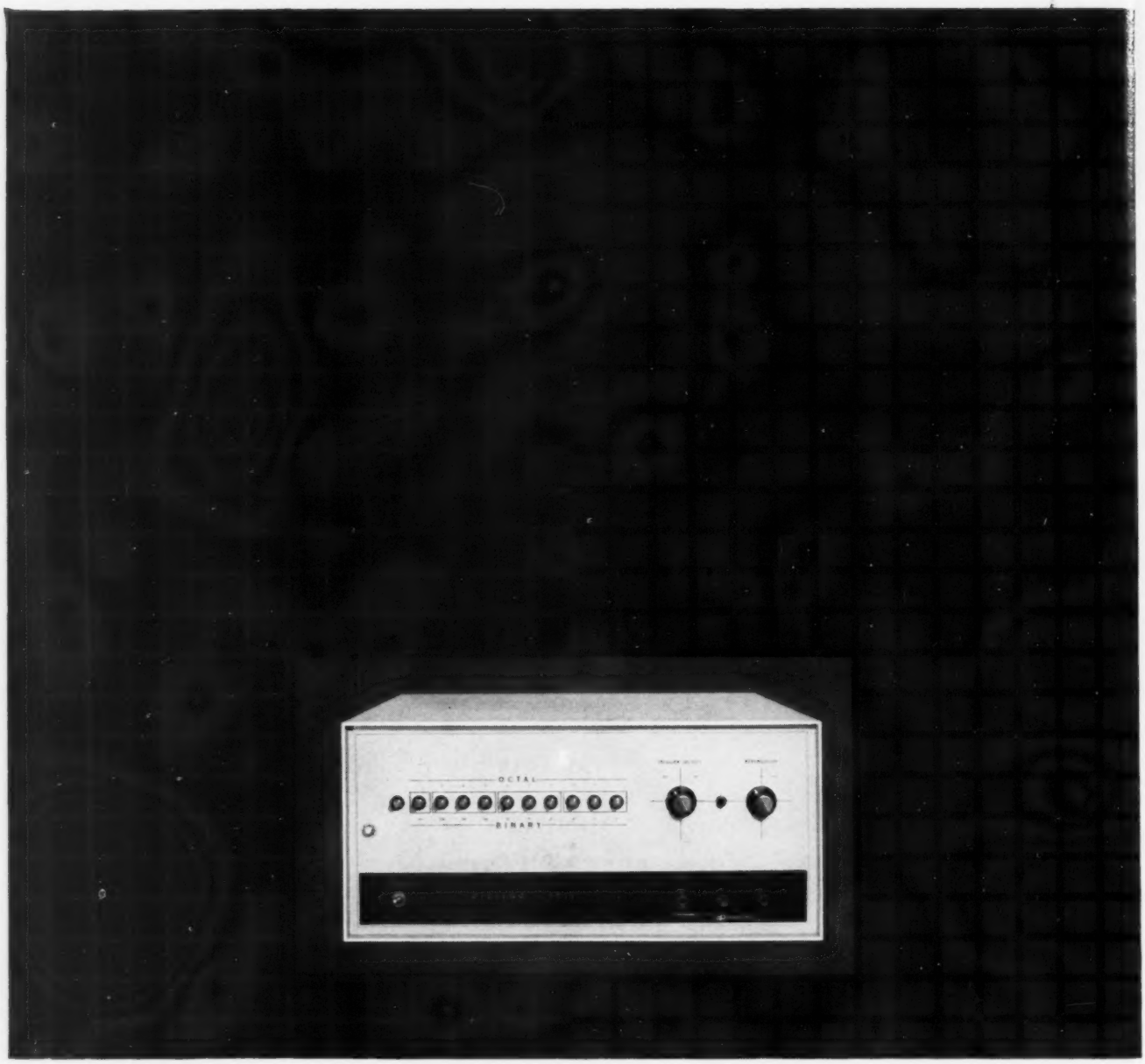
digest 24

SLIP RINGS

es Flora



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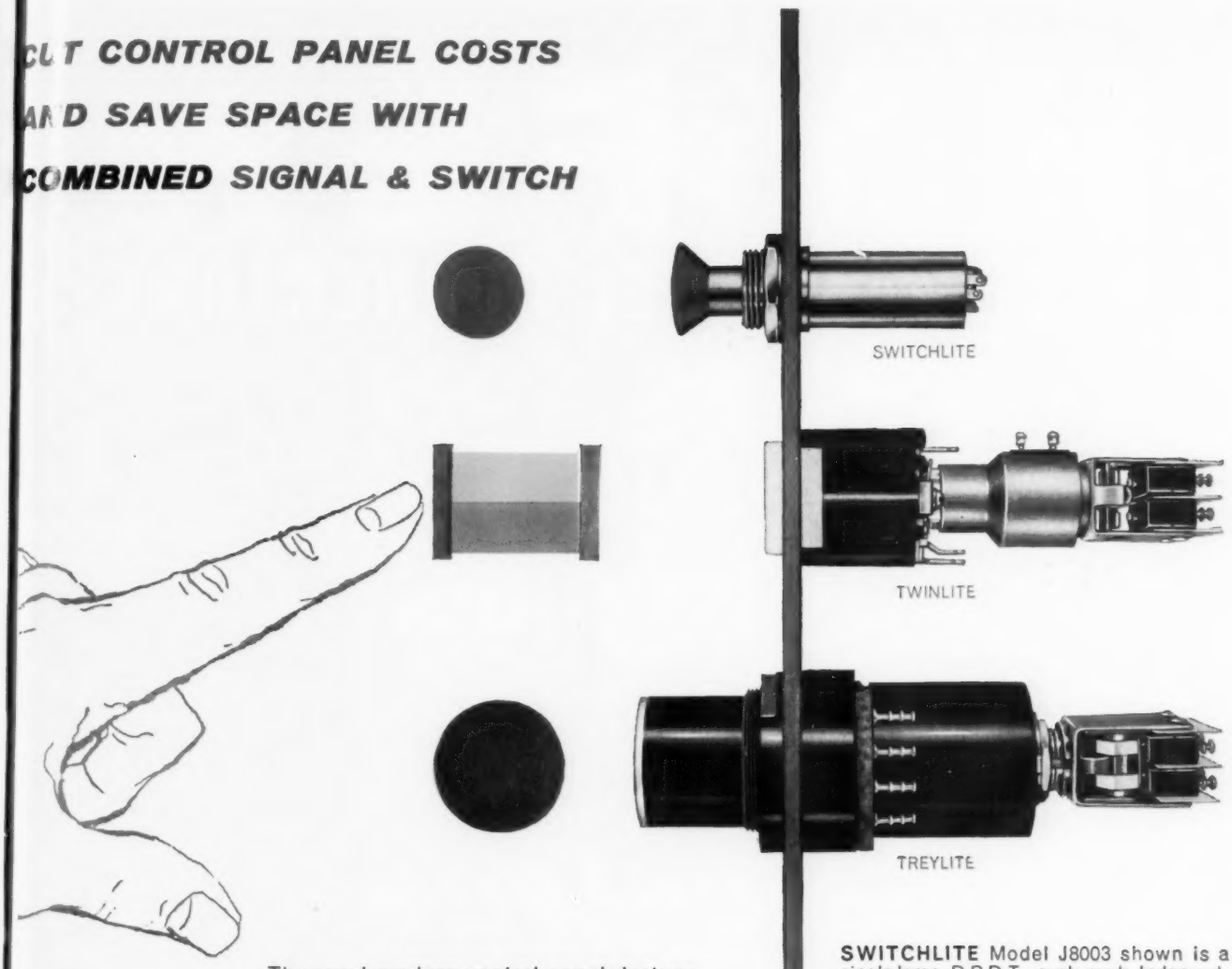
CIRCLE NO. 1 ON INQUIRY CARD

CUT CONTROL PANEL COSTS AND SAVE SPACE WITH COMBINED SIGNAL & SWITCH



The most modern control panel designs combine indicator lights and pushbutton switches wherever possible. This cuts costs by reducing the number of components, and speeds assembly. Overall panel size can often be reduced as much as 75%. And these "human-engineered" controls sell better because operation is obviously simplified. Here are just three of the many lighted pushbuttons available from Control Switch Division...

SWITCHLITE Model J8003 shown is a single lamp, D.P.D.T., push-push. Independent lamp circuit for 6, 14 or 28 volts. Rated 3 amp res., 1 amp ind. @ 28 VDC or 115 VAC. Mounts in ⅝" dia. hole. 4 button styles, several lens colors.

TWINLITE . . . two lamps with independent circuits for 2-color lighting. Lens 1" x .740" in solid or split colors, with or without nameplate slot. Momentary or push-push action, or solenoid-held switch shown above. Rated 4 amp res., 2.5 amp ind. @ 30 VDC; 5 amp @ 125/250 VAC. Mount in groups or singly, using barriers.

TREYLITE . . . three independent lamps, each with color filter so three colors can be sequenced on white pushbutton screen. D.P.D.T. switch rated 4 amp res., 2.5 amp ind. @ 30 VDC; 5 amp @ 125/250 VAC. Select momentary or push-push action. Models for flush-panel mounting (shown above) or subpanel mounting.

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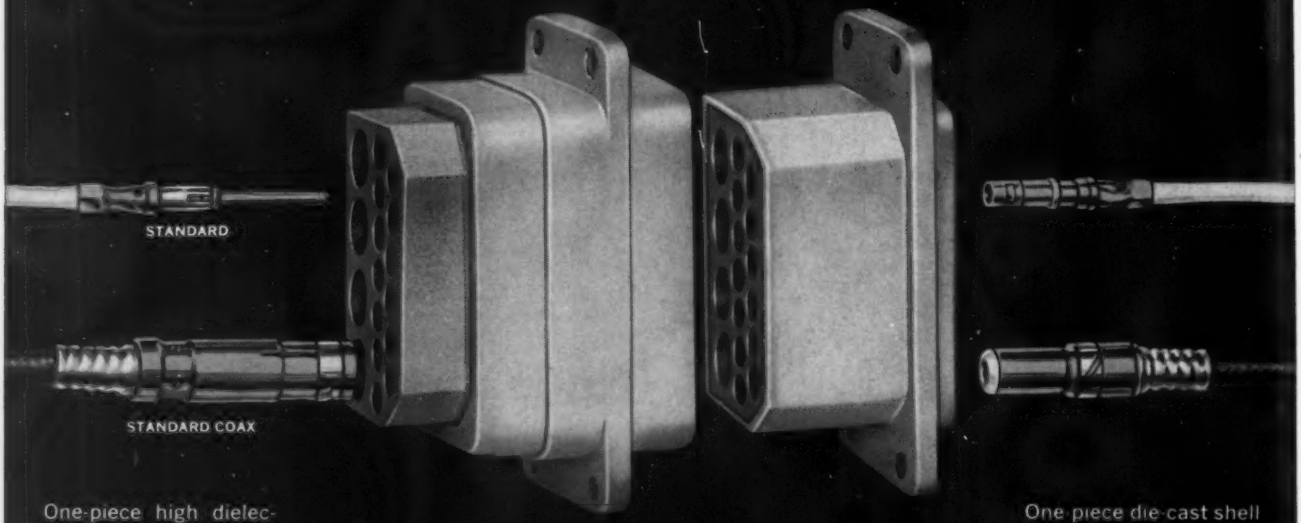
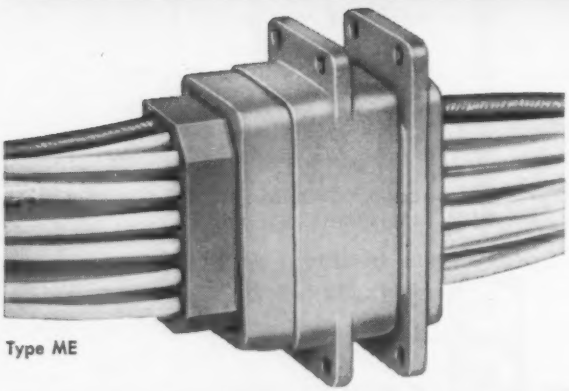


One-piece high dielectric strength insert contains molded-in ferrules for positive contact retention. Eliminates one cause of moisture entrapment.

Configurations accommodate three types of contacts: 1. Standard 2. Standard Coax 3. Miniature Coax (below), in any combination. All are plated in accordance with your requirements and are crimp-type, snap-locked HYFEN contacts.

One-piece die-cast shell design permits inserts to be interchanged in shells... allowing dead front in either plug or receptacle.

crimped-contact reliability—snap-lock versatility



Type ME

Burndy's line of rack and panel HYFEN connectors offers the high reliability of crimp-type, snap-locked contacts. The versatility of the HYFEN technique is increased by the accommodating of a wide range of wire types and sizes... coax, miniature coax and standard cable.

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CIRCLE NO. 3 ON INQUIRY CARD

ELECTROMECHANICAL
components & systems DESIGN

The Sourcebook of Design Ideas in Applied Electromechanics

NOVEMBER 1961 • VOL. 5 NO. 11

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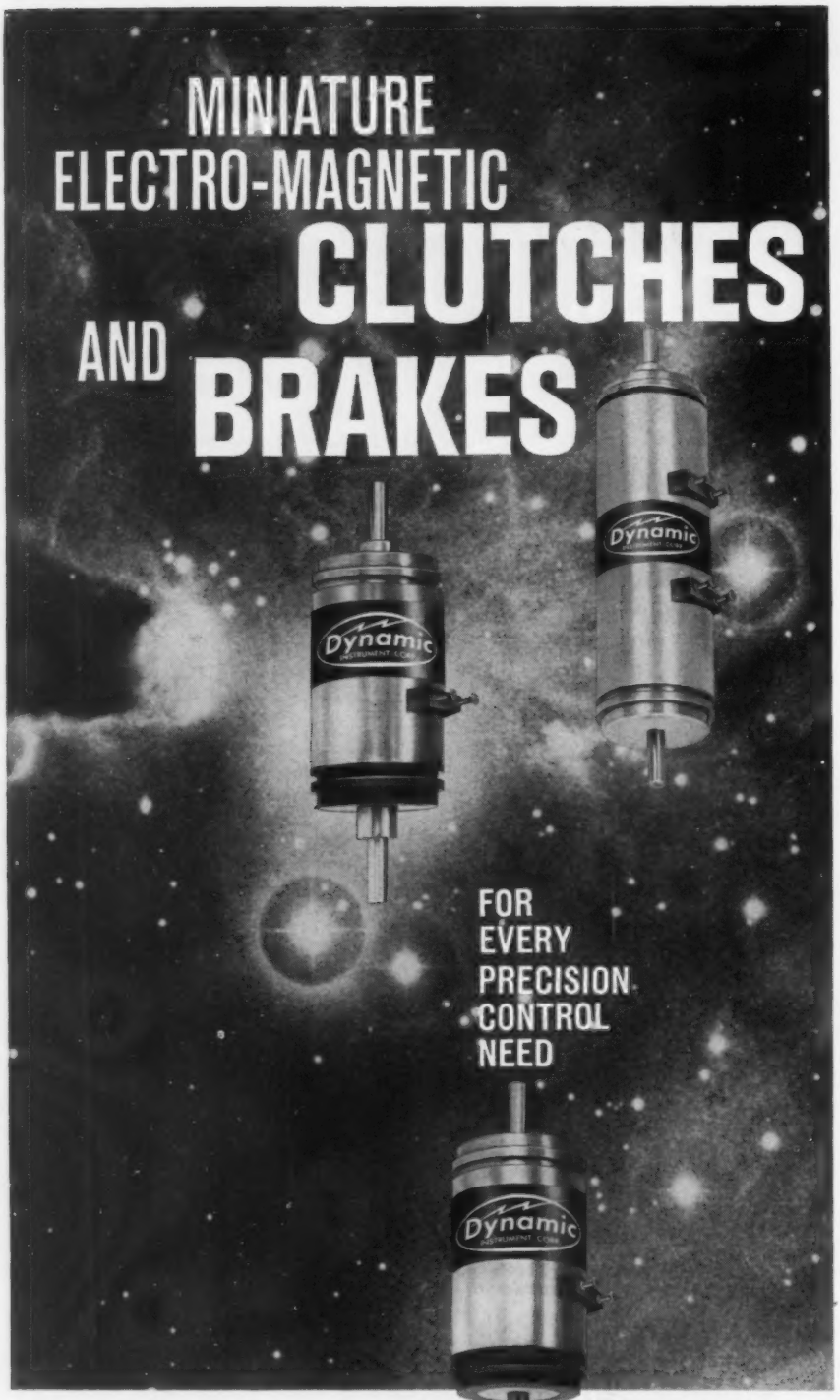

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BOOK REVIEWS

Transistor Logic Circuits

Richard B. Hurley, Advisory Eng., IBM
363 pages, $10.00
John Wiley & Sons, Inc.
440 Park Ave. So., New York 16, N.Y.

Covering both logical mathematics, logical routines and blocks and the transistor circuits that perform these operations, the author leads the reader from elementary binary arithmetic and Boolean algebra through minimization techniques and implementation concepts in the first part of the book. The second half contains a basic treatment of diodes and transistors in logic circuits. Application examples are used to clearly explain the integration of mathematics and devices into useful circuits. The techniques of sequential systems are covered in the latter part of the text.

Basic Concepts in Modern Mathematics

John E. Hafstrom
191 Pages, $5.75
Addison-Wesley Pub. Co., Reading, Mass.

This book serves as an introduction to some of the ideas and concepts fundamental to modern math. The book treats such topics as axiomatics and natural numbers, sets and logic, mappings and operations, groups, relations and partitions and the development of integers. Rational and real numbers are covered in the last two chapters.

Industrial Transistor & Semiconductor Handbook

Robert B. Tomer
265 pages, $4.95
Howard W. Sams & Co.
2201 East 46th St., Indianapolis 6, Ind.

Information on all types of industrial semiconductors, their operating characteristics, circuit design procedures, typical applications plus basic physics of semiconductor phenomena are all covered in 12 clearly-written chapters. Advanced manufacturing techniques are also described along with new areas of development – thermoelectricity, energy conversion, thin-film circuits and other techniques.

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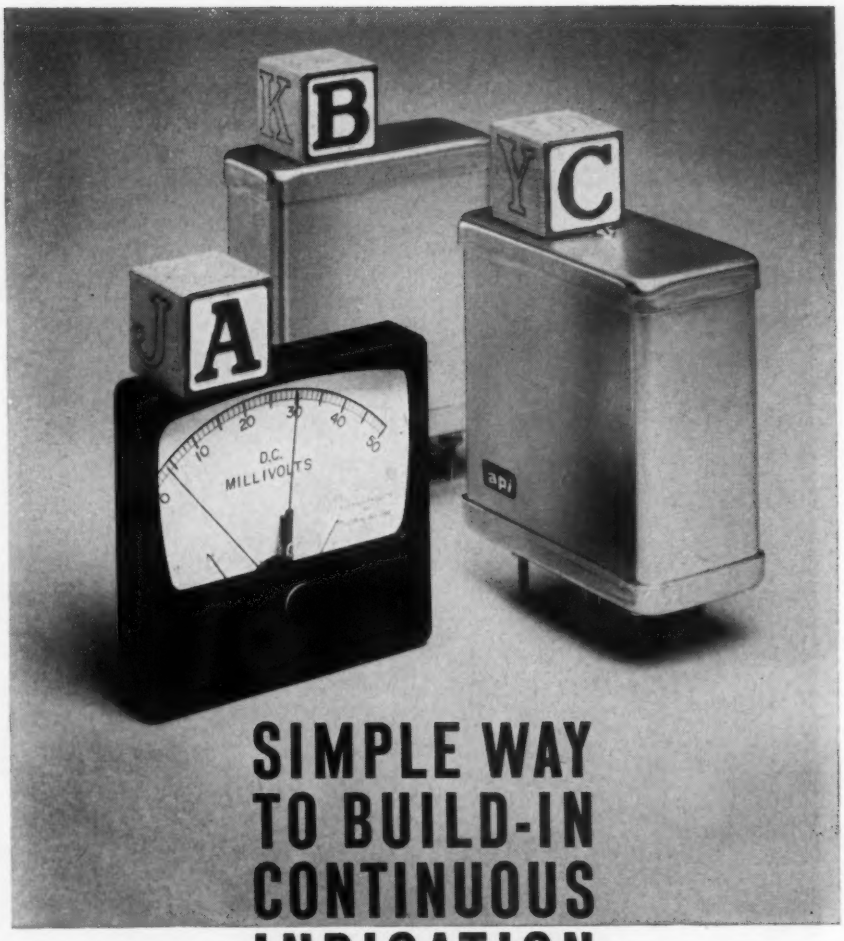

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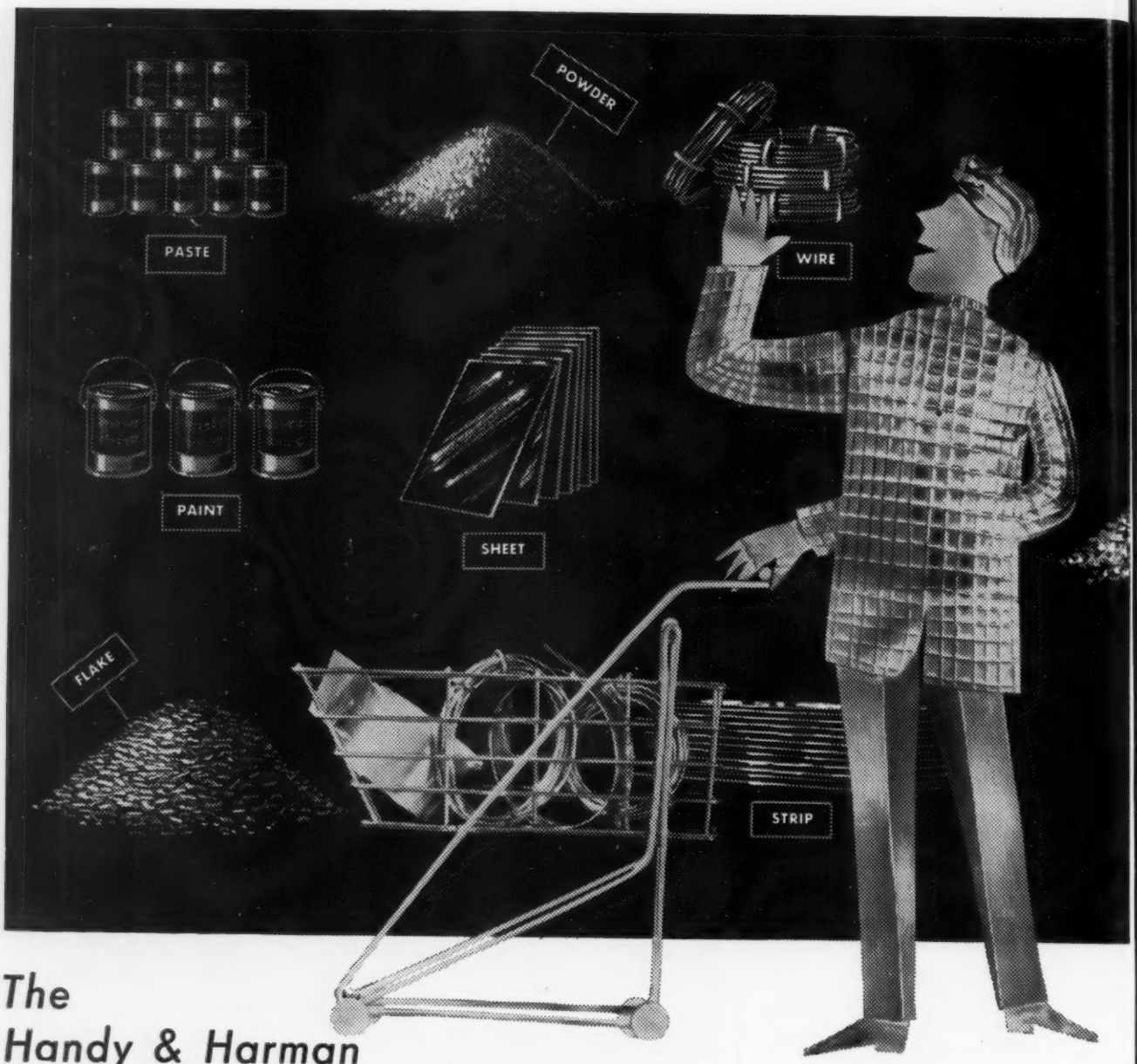

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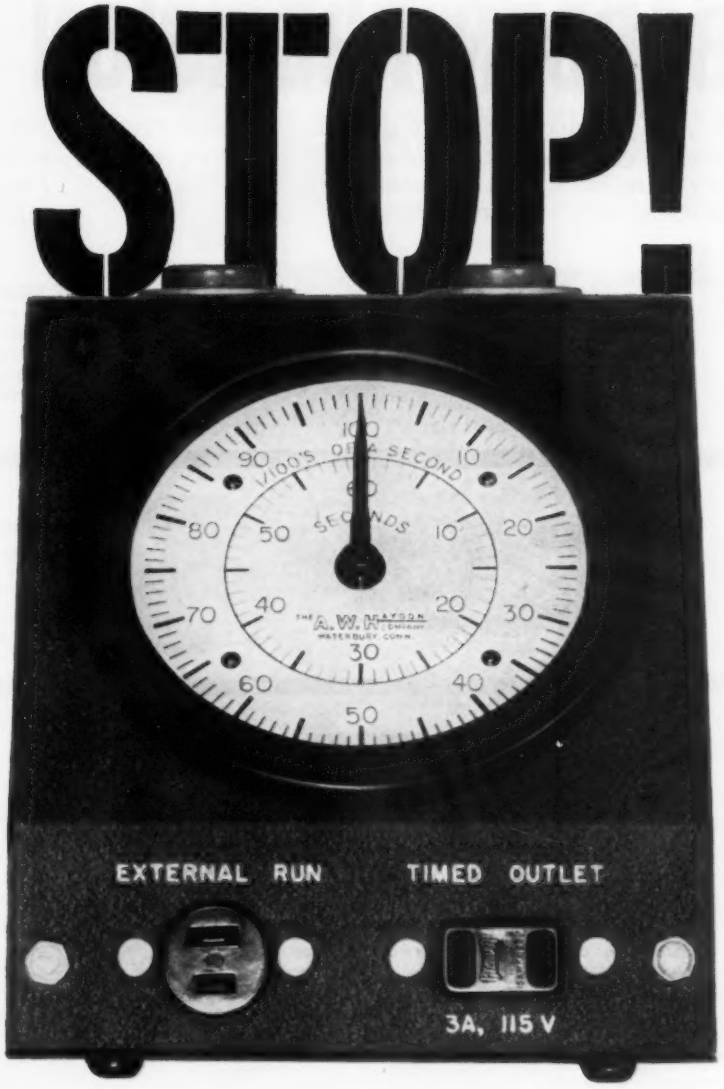

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CIRCLE NO. 7 ON INQUIRY CARD

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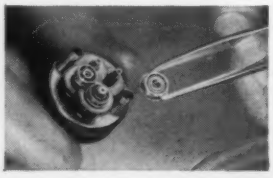

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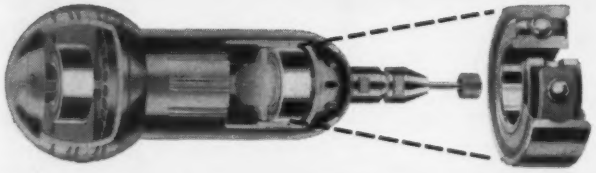
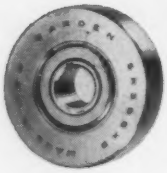
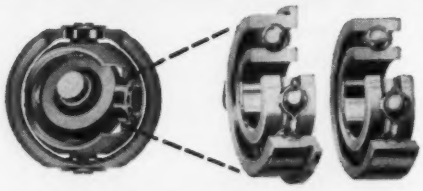


For power tools, aircraft and missile accessories, and other high speed applications: Barden "T" retainer bearings with high load capacity and long, trouble-free life. Double shielded, grease lubricated "T" retainer bearings have operated more than 6,000 hours at 80,000 RPM. Sizes from .5000″ to 3.3465″ O.D.



For synchros: Volume produced precision bearings with extra-large outer rings designed to serve as end caps, thereby reducing synchro complexity and cost and increasing air gap accuracy. Barden-developed synchro bearings have closely controlled radial play and minimum eccentricity to meet tight air gap specifications. Sizes from .3750″ to 2.0000″ O.D.



For gyro gimbals and other torque-sensitive devices: Barden "W" retainer reduces torque peaks and eliminates retainer lock. "W" retainer bearings save one gyro manufacturer $100 per unit by reducing costly teardown. Sizes from .1562″ to .6250″ O.D. Also other standard and special design gimbal bearings, including the Barden Dynamic Bearing with near-zero torque.

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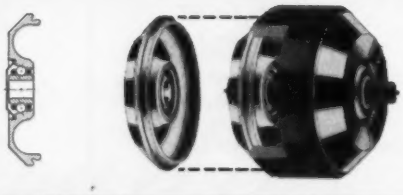

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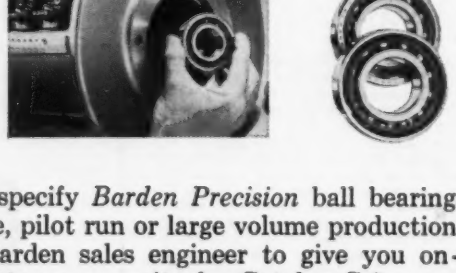

Major manufacturers of instruments, mechanical components, computers, spindles and aircraft accessories regularly specify *Barden Precision* ball bearings for high performance mechanisms.

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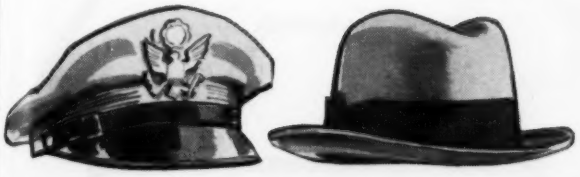

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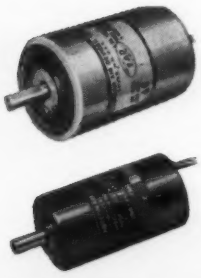

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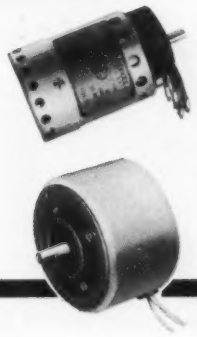

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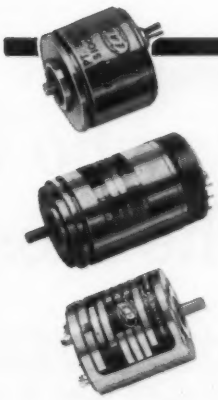

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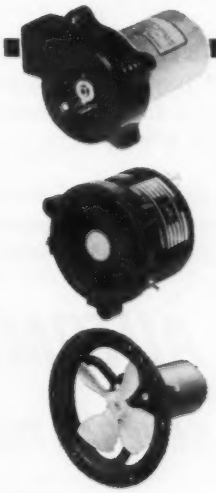

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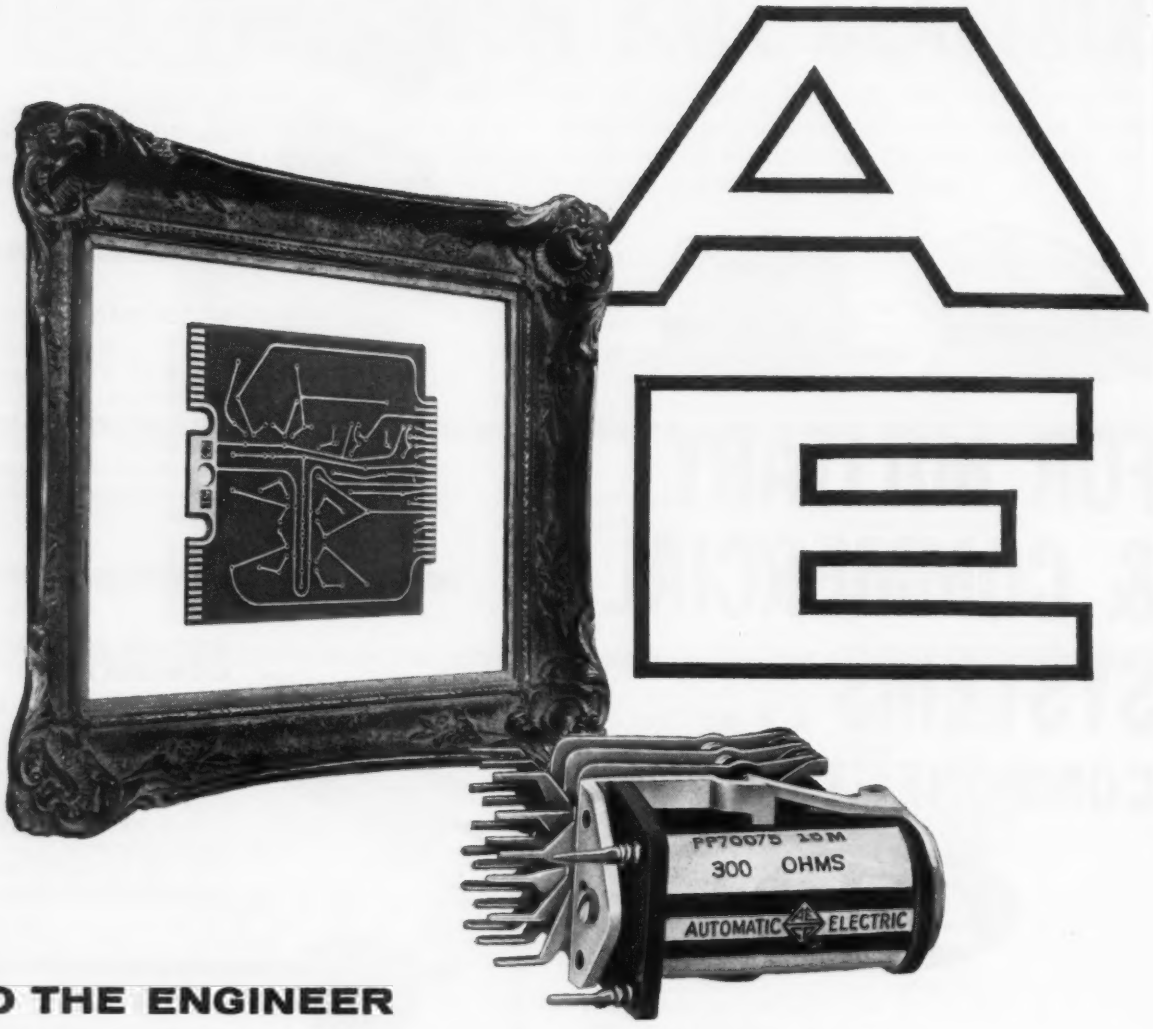

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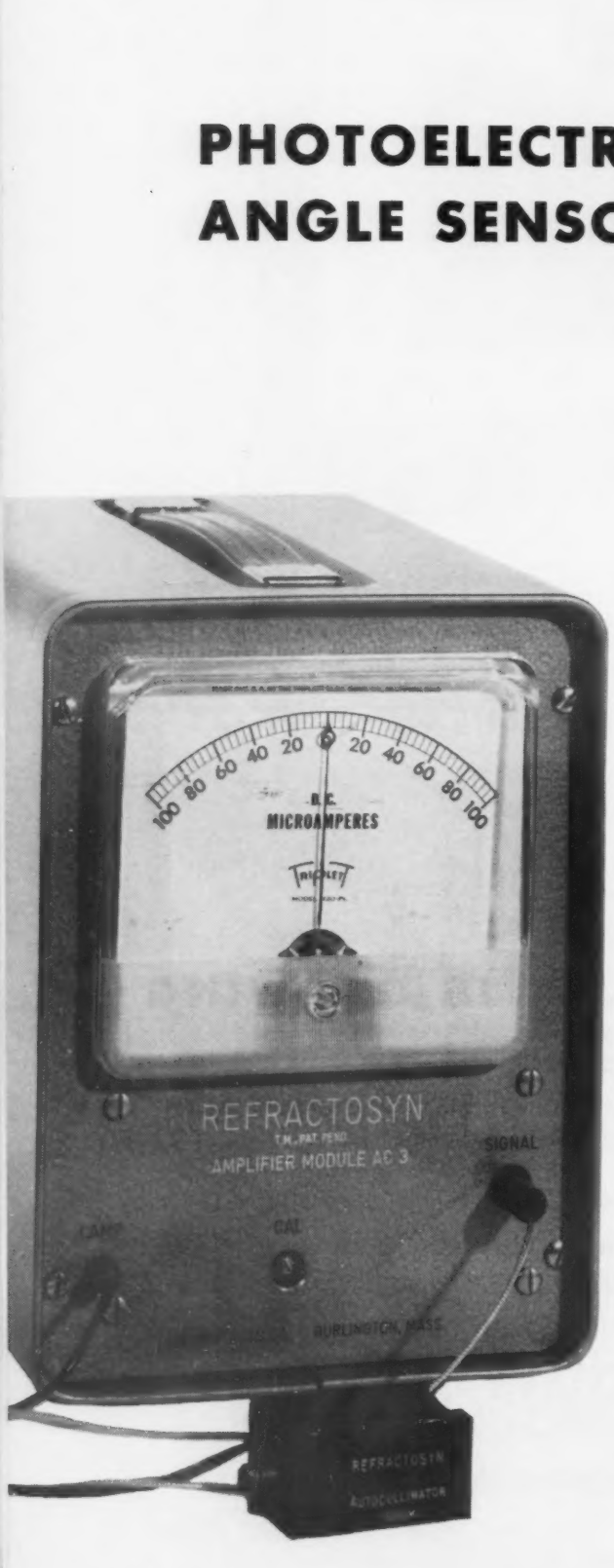

Optical instruments are generally used in making minute angular measurements where loading of the member being measured must be avoided. The technique has been to use imaging lenses, mirrors and long light paths as optical levers to transform the angle to position of a formed image. Position of this image is then sensed relative to a precisely indexed reticle. This method generally involves complex and expensive optics with long focal lengths.

A recent invention called the Refractosyn, by sensing the angle of incident light directly without recourse to cumbersome and expensive optics, now provides a most simple and compact method of measuring angles down to any degree of fineness required. Low cost and ruggedness of the device qualify it for many applications not feasible with other high priced instruments. It uses two photocells to sense the balance of energy refracted through a glass prism as the angle of incidence of a light beam to the face of the prism deviates from the critical angle. Figure 1 describes the basic principles of the instrument in more detail. Its extreme sensitivity is based on the well known refraction characteristics of a prism described in Fig 2.

Figure 2a illustrates the geometrical relationships for refraction of light from a prism face. Figure 2b plots the fraction of incident energy refracted as a function of angle of incidence. Theoretically, the curve approaches infinite slope as α approaches zero. An approximate analytical derivation shows that the refracted fraction of energy equals $8.7\alpha^{1/2}$. This means, for example, that as α changes from zero to 10^{-8} radians (0.2 arc sec) the refracted energy changes from zero to 0.87% of the incident energy, which quantity is sufficient to cause a significant signal from a photocell.

The remarkable performance and simplicity of the Refractosyn make it practical for applications wherever minute angular measurements are required. Figure 3 shows the standard configuration of the Refractosyn in the form of an electronic autocollimator. This device can be adapted to almost any instrument by affixing a half-inch square mirror to the moving member. Figure 4 illustrates its use as an optical strain gage. Compact, solid-state construction of the unit provides low-cost, low-power, reliable operation. It measures angles over a wide range, is unaffected by stray light or fields and has a wide-band frequency response.

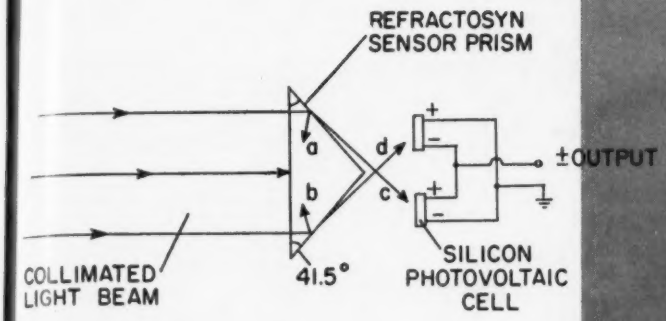

Fig 1 REFRACTOSYN SENSOR PRISM.
Collimated light enters through the hypotenuse face of the prism. The isosceles angles of the prism are made equal to the critical angle of the prism material, causing virtually all of the normally incident light to strike the sides of the prism at the critical angle and thus be internally reflected totally. Diffraction and chromatic effects cause a minute amount of light to refract through the sides and excite the opposing photocells, but since these signals are equal and opposing, the output signal is zero.

When the light enters the hypotenuse face at an angle slightly lower than the normal, refracted ray *c* is abruptly strengthened because the angle of incidence on the upper face is less than the critical angle. At the same time ray *d* is weakened because rays striking the lower face are incident at an angle greater than critical. Since the lower cell receives the stronger light signal, the net output voltage is positive. When the light rays enter from slightly above the normal, the alternate conditions exist and the output signal is negative.

Tests of the unit show sensitivity from 0.05 to 0.25 seconds of arc, and stability of one second of arc in 10 days. The only practical limitation on the life of the unit is the life of the light bulb, which varies from 1 to 4 years depending on the intensity at which it is operated. In most applications, where ultimate sensitivity is not required, the lamp can be operated at well under rated voltage to give maximum maintenance-free life.

Originally developed by Harold Seward at the M.I.T. Instrumentation Laboratory as a sun-sensor for an interplanetary spaceship, the Refractosyn has since proved useful at the Laboratory as an angle sensor for gyro testing, for gimbal alignment and for testing precision ball-bearings. Figure 5 illustrates the Refractosyn used as a ball bearing torque tester.

Commercial models of the Refractosyn Electronic Autocollimator (Patent Pending) and other instrument systems applying the Refractosyn principle are manufactured by H. H. Controls, 7 Leroy Drive, Burlington, Mass.

MEASUREMENT TECHNIQUES

Angular measurement with the Refractosyn Autocollimator may be made by several methods. The simplest method is direct measurement of the amplified photoelectric output, which has the advantage of high frequency response and the facility for direct recording or controlling. For most applications, the calibrated photoelectric output is entirely satisfactory.

Another method that can be used if the gain of the photoelectric loop cannot be stabilized sufficiently is to maintain the electrical output at null by manually rotating one of the glass plates (see Fig. 3). An indicator needle attached to this movement then registers any angular change on an associated scale. In this method, the reading is unaffected by changes in the photoelectric gain since that output is kept at null. The scale reading depends only upon the thickness of the glass plate and the focal length of the lens, both of which are constant and known. Disadvantages of this method are the requirement of manual servoing and reading and the lack of electrical output for transmitting, recording, or controlling. Moreover, the frequency response of the manual loop is very low.

Manual operation may be eliminated by em-

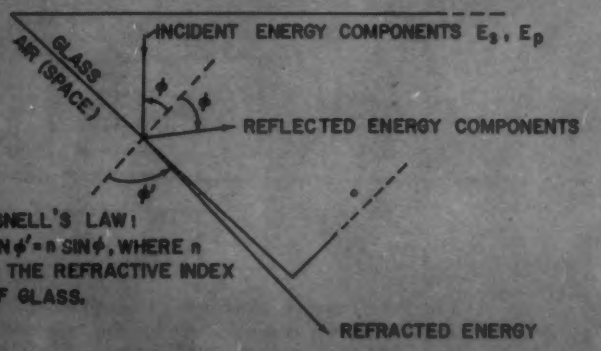

Fig 2a Geometrical relationships for refraction of light from a prism face. E_s and E_p refer to amplitude components of incident energy in plane normal to paper and plane parallel to paper respectively.

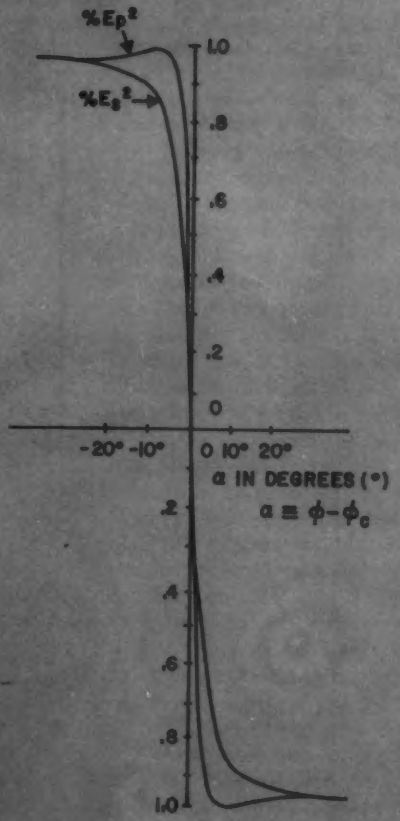

Fig 2b Fraction of incident energy on prism face that is refracted to photocells. In the diagram ϕ_c is the critical incident angle, where α is zero.

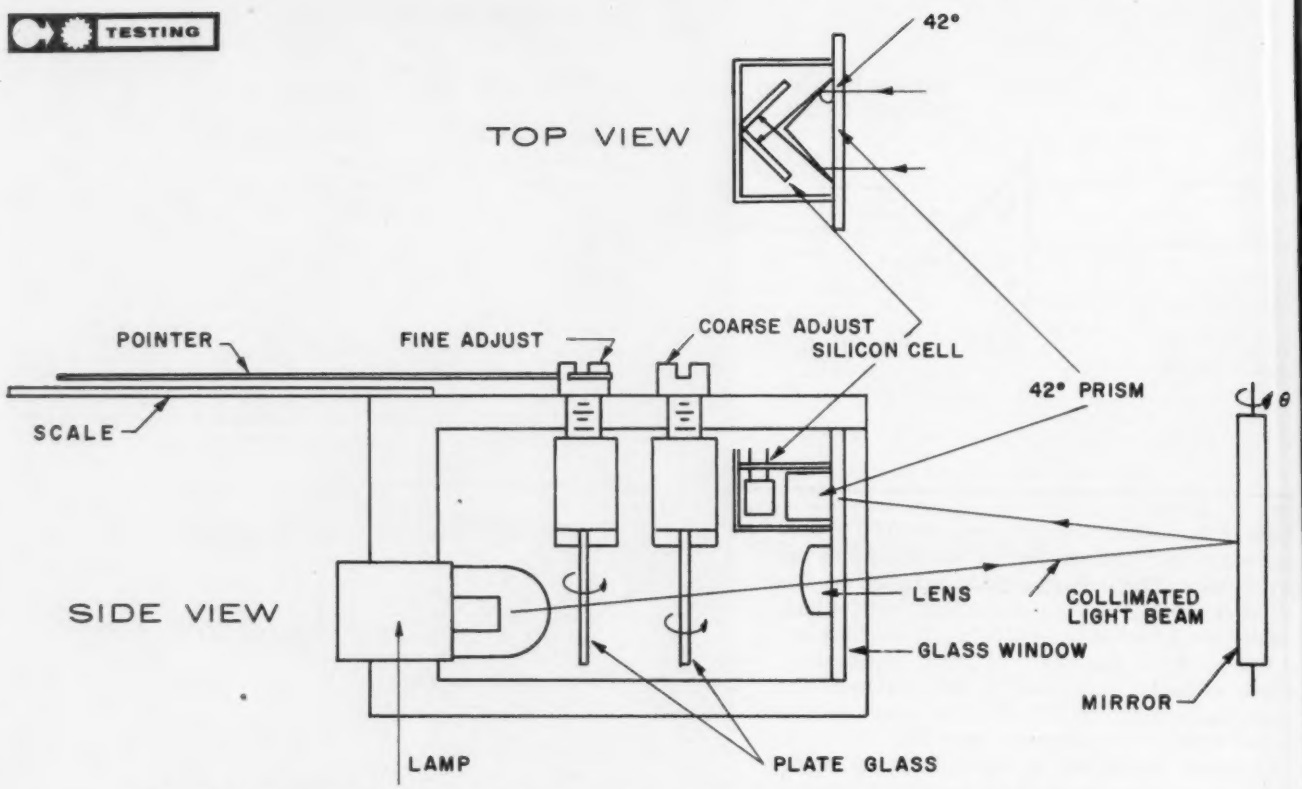

Fig 3 Refractosyn Electronic Autocollimator. Light from the lamp is collimated by the lens and directed to the external mirror. The reflected light is then directed to the Refractosyn prism and associated photocells. Any deviation in the direction of the reflected light will cause a corresponding signal at the photocell output.

Two flat glass plates, placed between the lamp and lens, provide a coarse (thick glass) and fine (thin glass) adjustment for initial zeroing of the Refractosyn. As the plate is rotated, the virtual image of the lamp as seen by the lens moves very slightly, causing a change in the direction of the collimated light beam. Initial zeroing is accomplished by rotating the plate(s) until the electrical output is nulled. Calibration of the gain of the Refractosyn may be accomplished by relating a fixed rotation of the glass plate to the full-scale electrical output.

ploying both electrical servoing and reading of the glass plate rotation. However, these features generally require a variety of servomechanisms, potentiometers, and associated electronics which dwarf the basic autocollimator. With the possible exception of a simple torque-to-balance coil movement, these components are to be avoided. The frequency response of the servoing method is an improvement over that of the manual method, but is significantly inferior to the response of the photoelectric output.

Another method is to operate the Refractosyn in the null region of both the photoelectric and the optical loops, thus eliminating the effects of gain change and also the necessity of rotating a glass plate. This method implies, however, that the reflecting mirror be restrained to its null region. Depending upon the requirements of the particular application, this technique may or may not be feasible.

An example of one such system is shown in Fig 6, where a galvanometer mirror is restrained to the null region by applying a portion of the Refractosyn output to the input of the galvanometer coil.

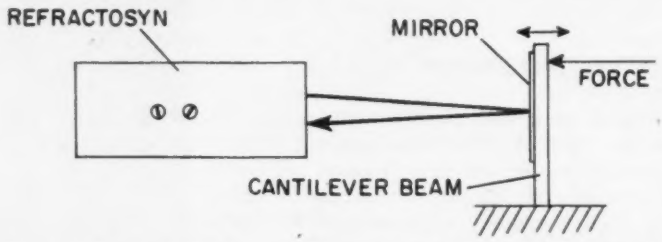

Fig 4 Refractosyn Strain Gage. Force input deflects cantilever and affixed mirror causing angular deviation in light beam reflected to Refractosyn. For a sensitive pressure gage, force might be supplied by a bellows. A sensitive temperature gage would result from use of a bimetal strip for the cantilever.

ADVANTAGES

Figure 6 illustrates many typical advantages the Refractosyn gives to such a staid instrument as the mirror galvanometer. The ordinary mirror galvanometer with a visual or photographic output is limited by the resolution limit imposed by the small size of the galvanometer mirror. Because the Refractosyn is able to detect angular position well below the resolving power of the mirror, much smaller galvanometer motions may be sensed easily. By employing feedback techniques, the galvanometer response time, input impedance, range, and period may be changed significantly and simply by positioning the selector switch. Electrical output is also available for recording. High sensitivity allows the use of a much stiffer sus-

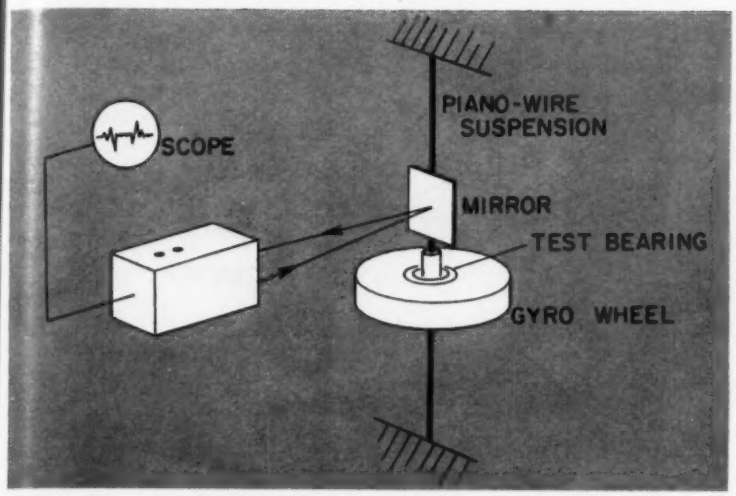

Fig 5 Refractosyn Ball-bearing Tester. The gyro wheel is caused to coast at a slow rate. Bearing friction and irregularities torque the piano wire resulting in mirror deflections. A recording of the Refractosyn output presents meaningful characteristics of the bearing.

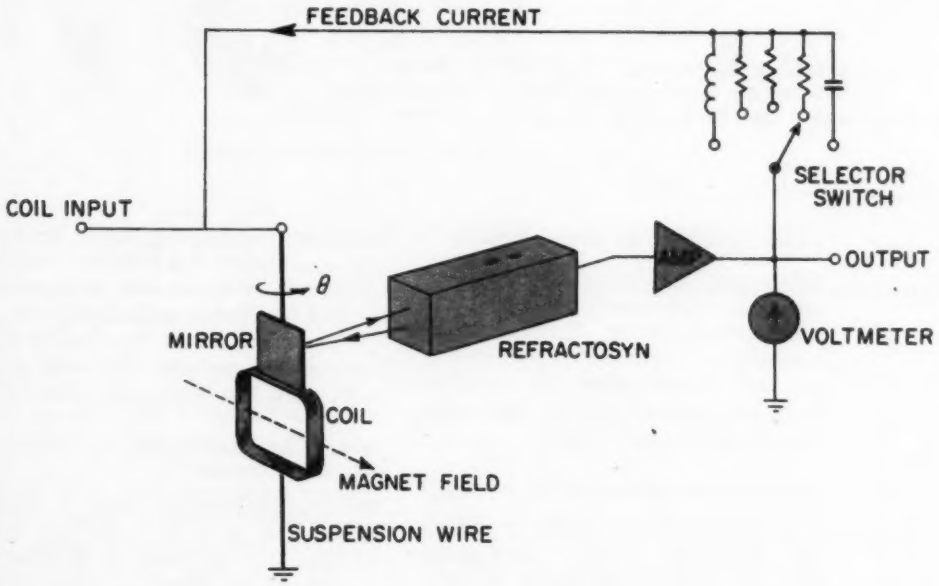

Fig 6a Refractosyn Galvanometer. Mirror restrained to the null region offers extreme flexibility in instrument characteristics, such as input impedance, period, range, damping ratio, etc.

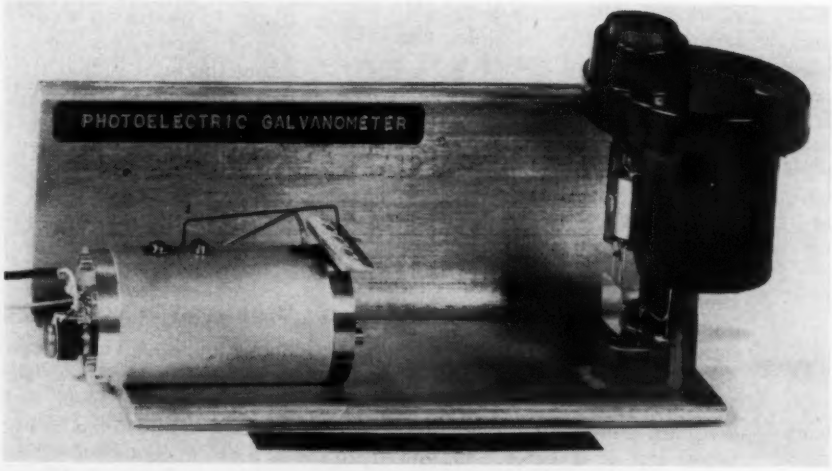

Fig 6b Model of a Refractosyn galvanometer.

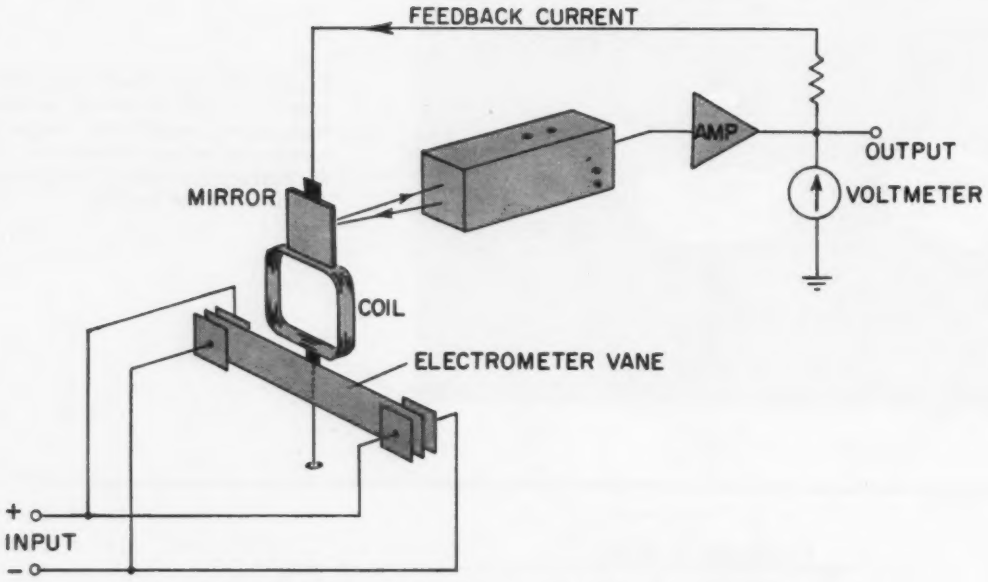

Fig 7 Torque-to-balance Electrometer. Input voltage charges electrometer plates causing electrostatic force on vane thereby twisting mirror. Galvanometer coil is used for feedback torquing to maintain null position.

pension wire, thereby making a more rugged instrument.

The many advantages of null-restrained systems are obtained in the system of Fig 6: effects of hysteresis in the spring, changes in spring constant due to temperature of deflection, changes in gravity forces, magnetic field changes or anomalies, magnetic impurities in the coil and non-linearities in general are all significantly reduced by restraint of the coil motion to a much smaller range.

Advantages of the Refractosyn application in the galvanometer system can be extended to many other types of measurement by mounting other transducers on the galvanometer coil-and-mirror suspension wire. A partial list of transducers that can be used are: wattmeter, dynamometer, balance scale, pendulum seismograph, densitometer, radiometer, Knudson vacuum gage. Figure 7 shows an electrometer vane attached to the suspension wire.

ELECTRONIC CONSIDERATIONS

Bandwidth and dc stability requirements for the Refractosyn vary with the application. The primary consideration in meeting these requirements is the method of amplifying the photoelectric signal.

AMPLIFICATION OF AC SENSOR SIGNALS

Where only alternating angular movements are to be sensed, an ac amplifier can be used directly. Selection of an appropriate amplifier and photocell is the only consideration. A tungsten lamp with dc excitation will generally prove best as a light source.

AMPLIFICATION OF DC SENSOR SIGNALS

Problems often arise, however, where non-alternating angular movements are to be sensed. With strong dc light sources, adequate output indication can sometimes be provided by connecting the photocells directly to a microammeter. For example, with the sun as the light source to a sensor prism with a 5 x 9 mm hypotenuse face, a sensitivity of 0.25 microamps per second of arc is nominal when silicon solar cells are used as the sensing elements. With a less bright light source, however, a galvanometer or dc amplifier is often required to obtain the necessary sensitivity. The galvanometer is restricted to fewer applications because it is limited by slow response characteristics and is generally delicate and cumbersome. The dc amplifier, if transistorized, does not suffer from these disadvantages, but it is subject to null drift even when it is stabilized with semiconductor-modulator systems. Mechanical-modulator stabilization reduces drift, but it introduces problems of limited life due to mechanical wear of the chopper contacts. Small offset voltages in the contacts also cause difficulty with low impedance photocells.

OPTICAL MODULATION OF DC SENSOR SIGNALS

The most effective solution to dc amplifier drift is to modulate the light by one of several methods to obtain a modulated dc signal so that an ac amplifier can be used. After ac amplification, the signal is usually demodulated to produce a phase-sensitive dc output signal. An advantage of modulating the light is that stray light signals are better tolerated, provided only that they are unmodulated or modulated at a frequency sufficiently removed from the signal frequency. Bandwidth of the system, however, is limited to less than half of the modulation frequency.

LIGHT-AMPLITUDE MODULATION

Some methods for modulating the amplitude of the light signal to the sensor prism are shown in Fig 8. The simplest is illustrated in Fig 8a, where an incandescent filament receives half-wave rectified excitation from a 60-

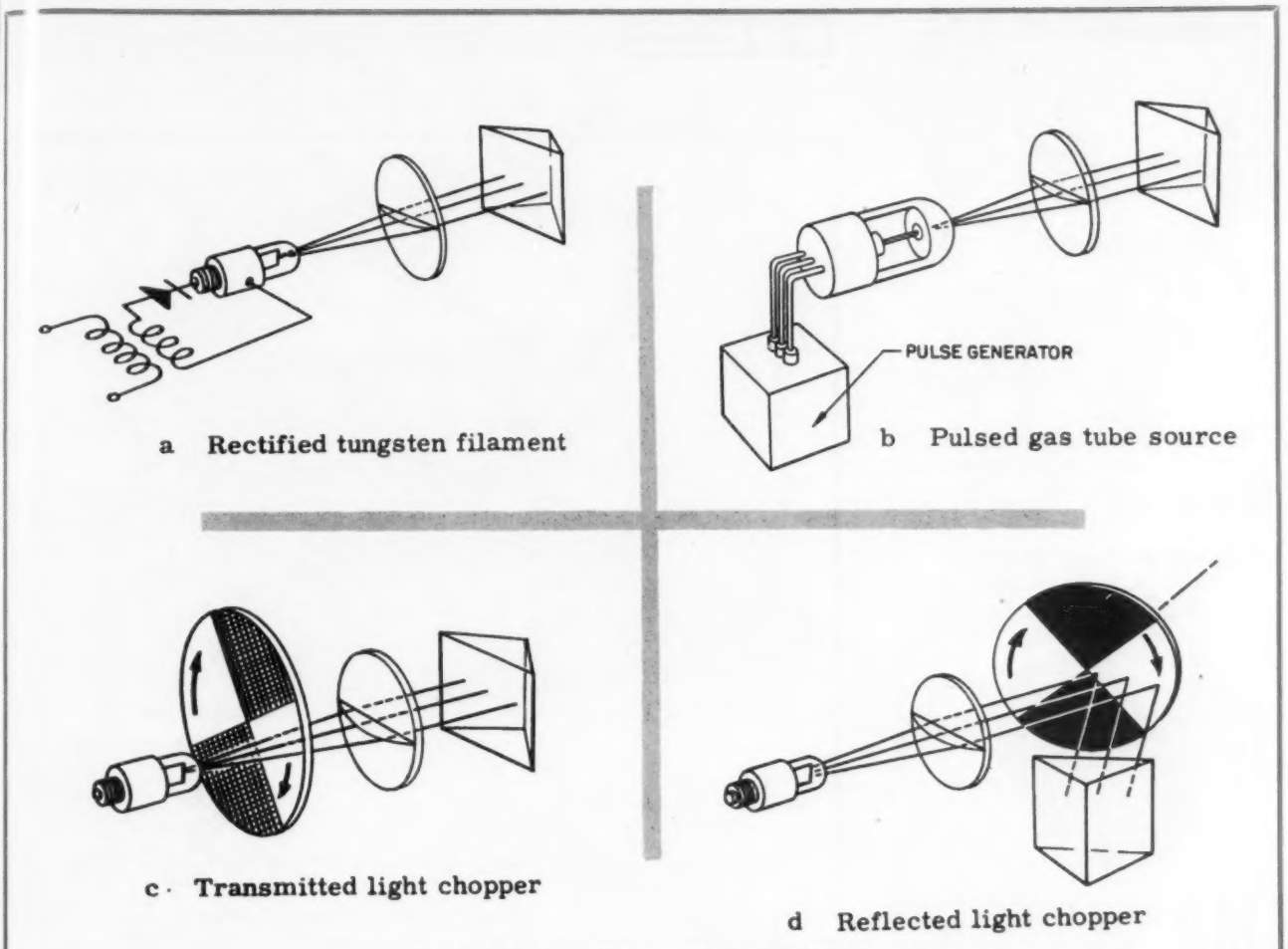

Fig 8 Methods of light-amplitude modulation.

cycle source. This is the method used in the Refractosyn autocollimator. The peak-to-peak ac silicon cell signal resulting from this fluctuating voltage on the lamp is about 20 to 50% of the total signal depending upon the bulb and voltage level. This loss of signal is generally insignificant when offset by the feature of completely solid-state operation.

Since the life of the bulb varies inversely with the 13th power of the voltage, designing the system for a life of several years of continuous operation is a simple matter. Although reduced lamp voltage reduces angular sensitivity, it is not as significant as the eye might expect, since the peak response of the silicon cells occurs in the near infrared wave-lengths to which the eye is insensitive.

Bandwidth of this system extends from dc to 20 or 30 cycles. If the rectifying diode shown is eliminated, a 120-cycle modulation occurs, which is about 10% of the total light signal. Although this result would double the bandwidth, ability to discriminate the phase of the output signal easily is lost without the diode. Higher frequencies, e.g., rectified 400-cycle, will allow larger bandwidth, but only at greatly decreased sensitivity. Modulation might be further increased with gas-filled tungsten bulbs, but this measure would be somewhat marginal.

Higher modulating frequencies are attained with pulsed gas-tubes as shown in Fig 8b. Bandwidths from dc out to many kilocycles may easily be realized. Disadvantages of this technique are the size of the tube, the special power source, and the limited life of the tube. Also, gas tubes that provide a bright point- or line-source (the latter being the most ideal for the prism sensor) are available in limited variety. Spectrally, gas-tubes are not generally well matched to silicon cells and, although they are reasonably matched to many photoconductive cells these cells are generally incapable of fast response, the presumed reason for using a modulated gas-tube.

Figure 8c shows a modulation technique using a rotating shutter with slits that alternately block and transmit the light at frequencies as high as megacycles depending on the number of slits used. In Fig 8d, the light is blocked or reflected by the rotating shutter. Mechanical wear, involved in this method, even at the low frequencies, means lower operating life and frequent maintenance.

LIGHT-POSITION MODULATION

A second method of providing modulated dc signals from the sensor is to produce a small angular oscillation of the incoming light about the sensitive axis of the sensor. In Fig 9a, a rotating wedge deviates the light to one side and then the other once per revolution. A rotating cocked mirror (Fig 9b) or an eccentric mirror-lens (Fig 9c) will create similar angular oscillations. As with the rotating shutters, mechanical wear is the principal disadvantage with these methods. But in addition, only one modulation cycle per rotation is possible whereas mul-

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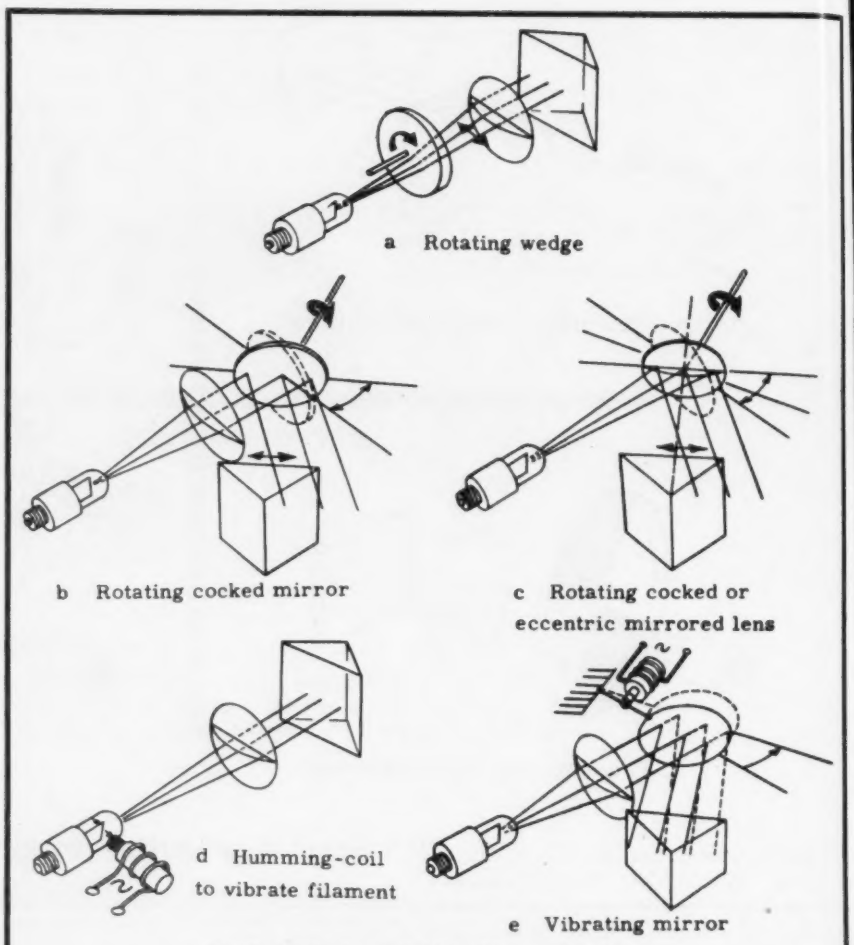
a Rotating wedge
b Rotating cocked mirror
c Rotating cocked or eccentric mirrored lens
d Humming-coil to vibrate filament
e Vibrating mirror

Fig 9 Methods of light-position modulation.

tiple slits on rotating shutters may provide several hundred modulation cycles per revolution.

Other methods of angularly oscillating the light source are illustrated in Figs 9d and 9e. Figure 9d shows a small iron-core or other transducer attached to the tungsten lamp. An ac excitation of appropriate frequency hums the base and vibrates the filament at near the resonant frequency. A natural frequency of a few kilocycles is obtainable in some small lamps. This configuration does not involve wearing parts. A small mirror on a resonating tuning fork, Fig 9e, might also be used but at lower resonant frequencies.

In all of these position-modulation methods, the two cells would be connected in an aiding, rather than an opposing configuration in order to create a usable signal. If possible, the two light signals refracting from the prism faces should be directed to the same area of a single photosensitive device. This design essentially eliminates any error caused by two separate photocells when their responses change differently. When the same area of one photocell is used, any change in the response of this area affects both light signals nearly equally, tending to eliminate any offset.

This feature may be particularly important in photocells where response is significantly affected by temperature, age, supply voltage, light level or spectrum, position, sensitive area, electrostatic or magnetic fields, etc. (Small silicon photovoltaic cells, when operated with zero voltage across them, are superior under these adverse conditions.)

One final note regarding amplitude vs positional modulation: with positional modulation, the output signal saturates as the angle from null approaches the magnitude of the angle of oscillation; with amplitude modulation, a reasonably linear range may extend for several degrees and gradually saturates near 30° from null, provided the cells are positioned to receive all the refracted light.

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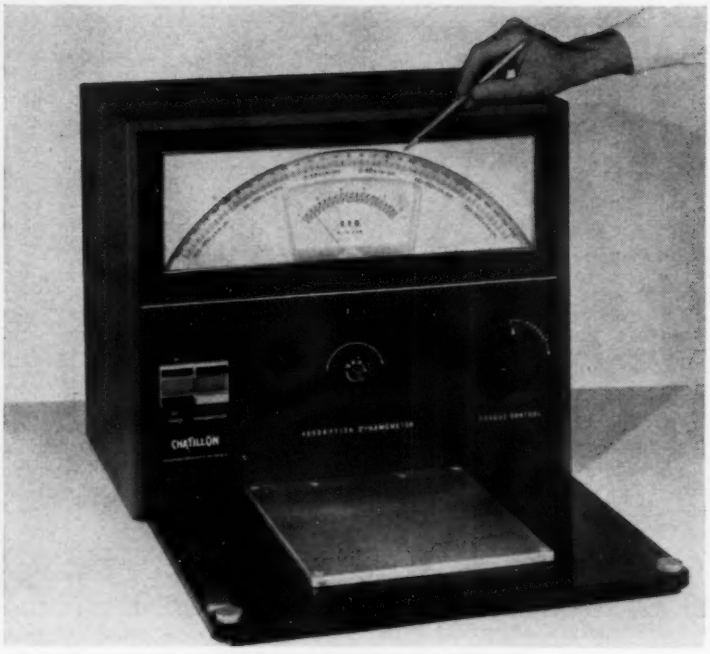

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Motor under test drives the brake's rotor which the magnetically coupled stator tries to follow, but is restricted by the reaction of the springs. The amount of this reactive force is transmitted to the unit's dial, where it is read in terms of inch-ounces, or inch-pounds. Photo-electric tachometer which is included as standard equipment eliminates mechanical contact between the shaft and transducer. Key to the design of the new hysteresis brake is the division of the new stator into two distinct elements. The heavy coil section is restricted from rotation, whereas the lighter second element, containing the magnetic poles, is directly attached to the indicating system. This reduces the starting torque of the system and also permits the use of smaller ball bearings which improves the unit's high-speed performance.

Another design innovation is the automatic transfer of torque ranges. Three separate torque systems, each consisting of a precision disc and spring, are mounted back to back. As the dynamometer measures the increase in reactive force, the first torque system actuates the second, and as the force continues to increase, the third is also actuated, thus accumulating the torques of the three springs and eliminating manual changing of springs, previously required for testing motors of different capacities. In addition, the new design does away with arbitrary selection of springs for testing motors of unknown characteristics.

Developed by John Chatillon & Sons, New York City, the dynamometer has an accuracy within one per cent and can apply clockwise and counter-clockwise torques without any set-up changes. Since it has a stationary field coil, there are no brushes, slip rings or moving wires, thus the inertia of the coil element is separated from the measuring mechanism aiding the pointer's sensitivity. For use as a static torque tester, a test fixture is supplied for dead weight checking of calibration.

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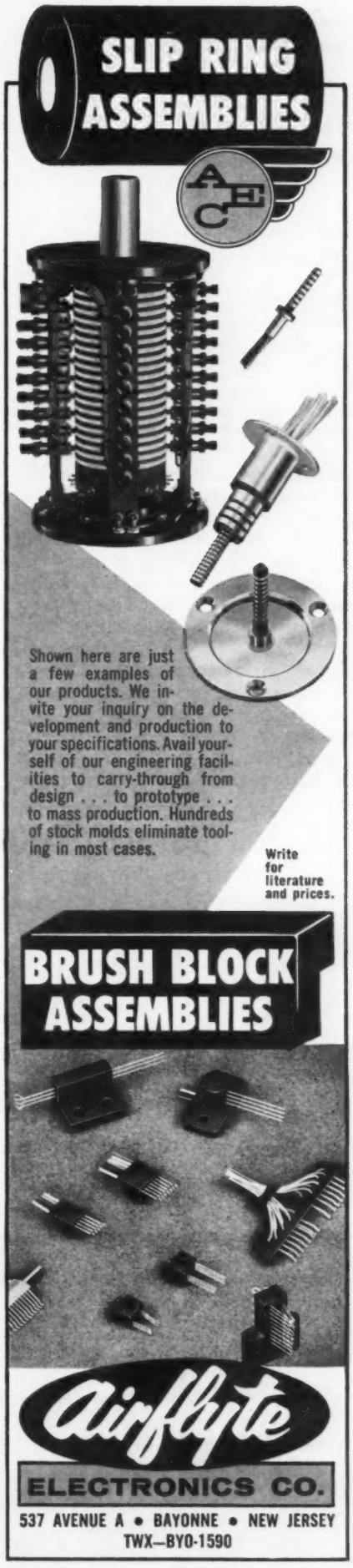
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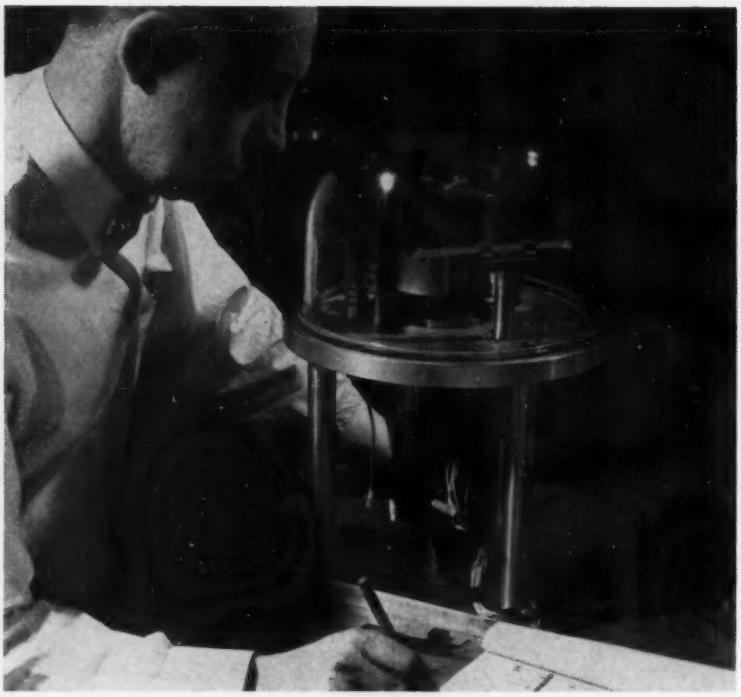
Precisely reproducing the major characteristics of critical friction-easing bearings, Sperry Gyroscope's ball bearing simulator opens the way to quick, but comprehensive, evaluations of a multitude of lubricants, contaminants and other materials and their effect on bearing life. According to reports, Sperry has simulated bearing life tests in only one-tenth the time required for a run-to-failure checkout.

Three Sperry simulators, believed to be the only machines of their kind in existence, are presently able to duplicate the performance of any high speed, high temperature, low lubricant bearing, such as those employed in miniaturized gyroscopes, motors or computer memory drums. Improvements in the simulator, according to Sperry, promise effective use of the test device for a much broader range of industrial bearings.



Enclosed under a sealed glass cover, the Sperry table-top device exactly simulates operating temperature, atmosphere, ball-to-race contact pressure and surface speed, roll-to-spin ratio and amount and type of ball lubricant. Simple and inexpensive construction makes the simulator especially attractive, Sperry scientists said. Parts are easy to manufacture with simple machine tools. Race or ball track surfaces are flat, and can be exactly duplicated as often as necessary.

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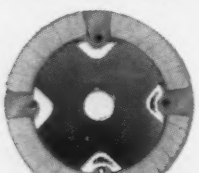

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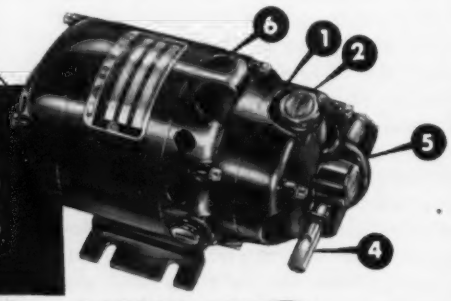

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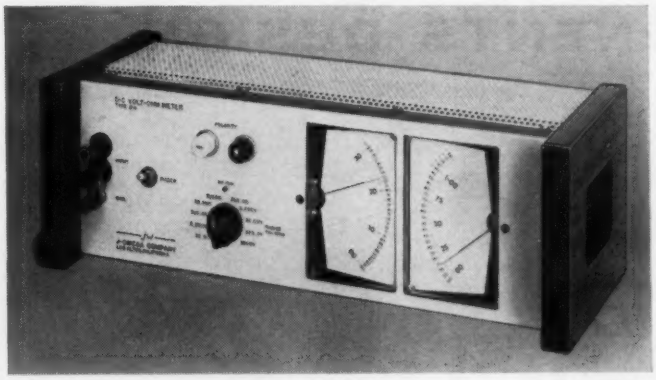

SEMI-DIGITAL VOLT-OHMETER

Accuracy at Relatively Low Cost

Recognizing the need for an instrument that gives the accuracy of digital circuitry without the usual complexity, J-Omega Co., Los Altos, Calif., has developed a general purpose volt-ohmeter that combines the simplicity of analog circuitry with digital accuracy. Two conventional D-Arsonval meter movements are so arranged that the "resolving power" of one acts to multiply the resolution and accuracy of the other. Result is accuracy approximately to three significant figures.

Operator reads two meters; left-hand meter acts as a digital indicator. Its scale is calibrated in 32 steps (0 through 31). Associated circuitry feeds this indicator a quantized current so that it always points to one of the 32 graduations. Right-hand meter movement, connected to analog circuitry, is calibrated 00 to 120 while the span from 00 to 100 corresponds to one step of the digital-indicating meter. For readout, the operator reads from left to right, obtaining two figures from the left-hand indicator and two additional figures from the right-hand indicator.

For voltage measurements, an additional binary circuit is used to indicate polarity. Two clearly-labelled pilot light readouts are color coded to minimize possible error. Only one tube is used (for high input impedance). Accuracy is ±0.15% of full-scale at the top of each range, improving linearly to ±0.05% of full-scale at the bottom of each range. Bench or rack type is priced at $650.

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PHASE ANGLE METER 729

combines the functions of an ac voltmeter, phase meter, phase sensitive null indicator, power factor meter and measures separately the in-phase and quadrature components of a signal. Unit features a rugged MIL-type, hermetically sealed meter, shielded inputs for signal, reference, power and chassis ground, plug-in, and all solid state amplifiers. The meter is available for 115 volt operation with signals of 400 or 800 cps. Twelve ranges of voltage measurement cover from 1 mv to 300 volts full scale. Accuracy as a phase angle is rated at ±3% full scale, using E cos θ characteristic and ±2% of full scale as an ac voltmeter. For phase angle measurements a front panel switch permits choice of a 0 or 90° reference or use of a variable phase trim. In the phase sensitive operating mode the null sensitivity is 2 microvolts and harmonic rejection is greater than 55 db. No. Atlantic Industries, Inc., Plainview, N.Y.

VOLTAGE COMPARATOR, 734

T-172, is a transistor circuit module that can detect d-c voltage levels in the range of −6VDC to +6VDC. The unit contains a differential amplifier that drives a pre-biased squaring amplifier to provide a well defined voltage switching point. Sensitivity is 0.1 volt over the temperature range of −54 to +71C. Packaged in a container 7/8" dia. by 2-3/16" seated height, the unit plugs into a standard 9-pin miniature tube socket. Engineered Electronics, Santa Ana, Calif.

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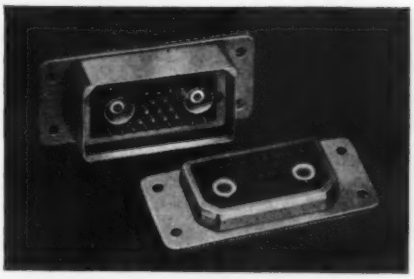

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■ *Write Dept. 511-W for Series S-20 Dimensional Data Sheets*

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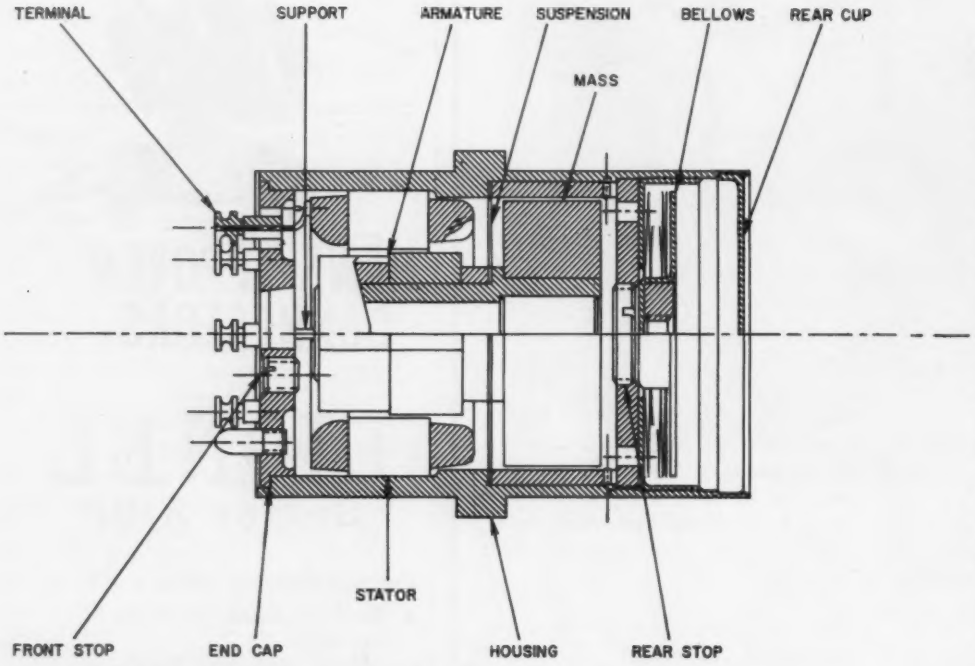


U. S. Time's non-pendulous linear accelerometer with variable reluctance pickoff, linear fluid damped mass and frictionless suspension. Damping ratio is maintained essentially constant over the temperature range by means of nylon compensator which controls the size of an annular damping gap. The pickoff armature is part of the seismic mass. As an acceleration is applied to the instrument along the sensitive axis, the armature is displaced with respect to the stator, thus producing an electrical output proportional to acceleration input. The configuration is extremely versatile, making it simple to modify the basic design to satisfy a multitude of accelerometer applications. Important characteristics are: 1 inch diam. by 1¾ inches long, linearity ±0.2% of full scale to ½ full scale and ±1% full scale to full scale, threshold 0.0001 G typical, cross axis sensitivity 0.003 G/G typical, shock to 100 G's, vibration 30 G's to 2000 cps.

SUBMINIATURE LINEAR ACCELERATOR

Larger, Stronger Parts Improve Reliability of Miniature Instruments

Demands for smaller and smaller precision gyros and accelerometers with improved performance and reliability have pushed the art of the instrument maker near the limit. Resulting problems have attracted many watchmakers and watch manufacturers to the instrument industry where their special skills in design and manufacture of miniature precision equipment at low cost have been recognized.

An example of the watch manufacturer's contribution in this field is a subminiature, non-pendulous, linear accelerometer recently announced by the Instrument Div. of U. S. Time Corp.

Weighing less than three ounces, the new instrument described in the accompanying figure, is less than half the size of previous miniature units, has fewer than half the working parts, and is more sensitive than many larger models that cost many times more. An important application of the unit will be in separation techniques by which missile stages are dropped. It will also be used to correct for errors in missile computing systems where side accelerations have to be measured.

The big problem in the design was building into a unit this small the basic accuracy required and the capability to measure very low to very high accelerations.

Engineers were able to achieve minimum cost and subminiaturization by maximum utilization of each of the parts within the instrument. Hermetically sealing and filling the unit with damping fluid gives the accelerometer high resistance to shock, vibration and temperature. Damping is essentially constant over the wide temperature range of −65°F to +250°F without the use of heaters.

Reliability was achieved in the design by careful adherence to a U. S. Time design principle: use as few parts and components as possible and make them as strong and large as the overall design permits. The assembly is held together by accurately controlled interference fits or by husky threaded fasteners. No miniature screws are used; only one rather heavy clamping ring is required to assemble the accelerometer mass into the housing.

FRICTIONLESS SUSPENSION

A web-like structure supports the mass and furnishes spring restraint with good linearity. Very high torsional stiffness of the suspension, together with insensitivity of the pickoff to small angular deflections, insures negligible sensitivity of the instrument to angular accelerations. High ratio of radial to axial stiffness of the suspension, together with precision housing design to prevent misalignment of mounting surface and sensitive axis, minimizes cross axis sensitivity (cross talk). The suspension is designed so that the spring rate can be varied and controlled to close tolerances.

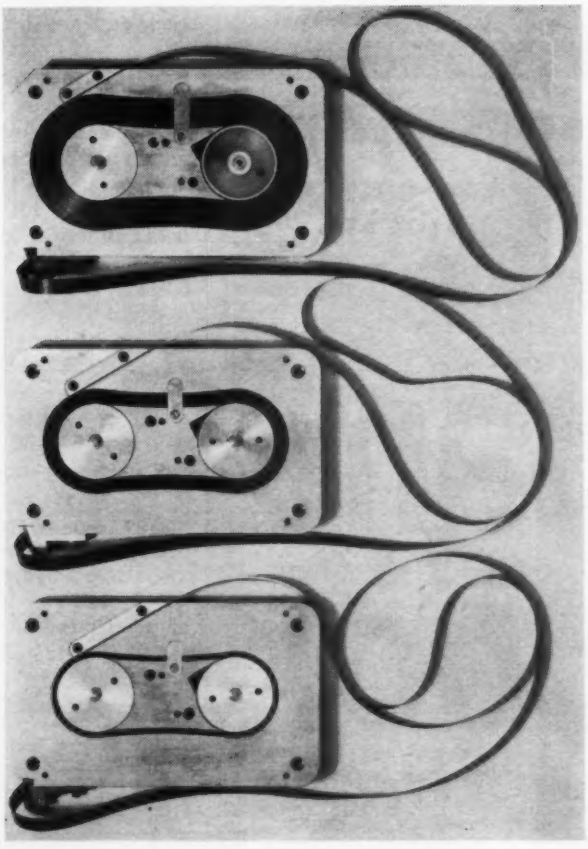
MASS AND DAMPER

The mass consists of a shaft, the pickoff armature and a nylon piston. Expansion of the angular damping gap of the nylon piston with temperature compensates for effects of temperature on damping fluid viscosity.

For a given G range, the natural frequency of the accelerometer can be varied over a wide band, by making discreet changes in the geometry of the mass thereby varying the amount of fluid coupling under dynamic inputs.

Write No. 291 in Box on Inquiry Card

Speidel's Inertia Compensated Recorder operates from a 28 vdc supply. Total power required is approximately 50 watts at a tape speed of 60 ips. At this speed, signals up to 100 kc can be recorded. Unit was used successfully by the GE in test flights of the Atlas ICBM re-entry vehicle and also by Lockheed Corp. in Discoverer capsule which was recovered after orbiting the earth.



Tape magazines, used in Speidel's recorder, contain different lengths of ¼ inch, 1½ mil Mylar tape with two tracks. Signals from a missile's instruments are recorded on both tracks. Tape moves through the magazine and reappears at the playback head after a predetermined delay time. If a communication black-out is expected to last for a 20 second period, the length of tape in the magazine would be sufficient for recorded signals to be delayed at least 20 seconds before being reproduced.

MISSILE TAPE RECORDER

Immersing Tape in Liquid Reduces Inertia

During re-entry phase of missile flight, conventional continuous loop recorders, with one hundred feet of tape, have to withstand high acceleration forces. To meet this problem, in the design of their magnetic tape recorders, Speidel Corp. immerses the tape in a liquid which has the same specific gravity as the tape. Thus, according to Richard V. Monopoli, Project Engineer at Speidel, inertia forces acting on the tape are almost eliminated. The recorder holds a continuous loop of tape in a magazine which is 3 inches by 5 inches by 0.5 inch.

Use of the liquid introduced several problems which do not arise in the design of conventional recorders. Liquid film, between the tape and record and reproduce heads, must be almost completely removed for satisfactory frequency response. Speidel accomplished this removal by running the tape over a corner whose radius is about 0.004 inches while simultaneously subjecting the tape to a pressure pad force of 10 to 15 grams. This procedure reduced the liquid film to a thickness of 1 micron which is tolerable for frequencies to 100 kc.

Liquid film between the tape and the rubber capstan was also a problem. Slip between capstan and tape would normally occur due to lubrication caused by the film. Speidel's method for providing intimate contact between the tape and the capstan's circumferential surface was to construct, around the capstan circumference, a number of slits extending at an angle to the longitudinal center line of the tape. This design gives the required traction by removing the fluid film from between tape and capstan surface.

Servo controlled dc motor drives the capstan at a constant speed through a worm gear reducer. A mechanical filter reduces wow and flutter by eliminating some of the predominant frequencies that originate in the worm gear. Since the tape speed is fixed to obtain a certain frequency response, the delay time must be varied by using different lengths of tape. Replacing the readily accessible tape magazine with one containing a different length of tape changes the delay times.

Speidel's Inertia Compensated Recorder is a rugged, compact unit specifically designed to withstand the environmental conditions encountered during a missile's flight. Its overall weight is approximately 10 pounds and it records and reproduces up to 26 FM modulated standard IRIG subcarriers in the frequency range from 1 kc to 100 kc, 13 on each of two tracks. Subcarrier signals must be mixed prior to being sent to the recorder. Signal input voltages over a range from 0.1 volt rms to 1.0 volt rms can be recorded. Output voltage level is adjustable from 0.1 volts rms to 1.5 volts rms by setting the gain of the playback amplifier. Output level is constant within ±1.5 db from 1 kc to 100 kc.

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COMPONENTS DIGEST

handbook 1

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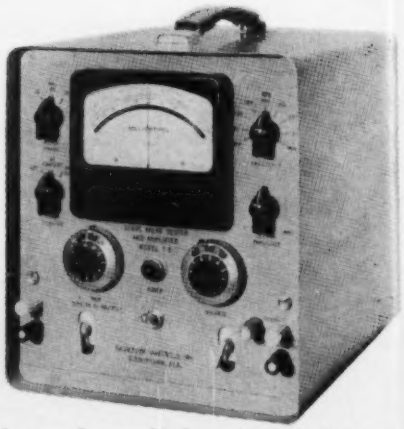
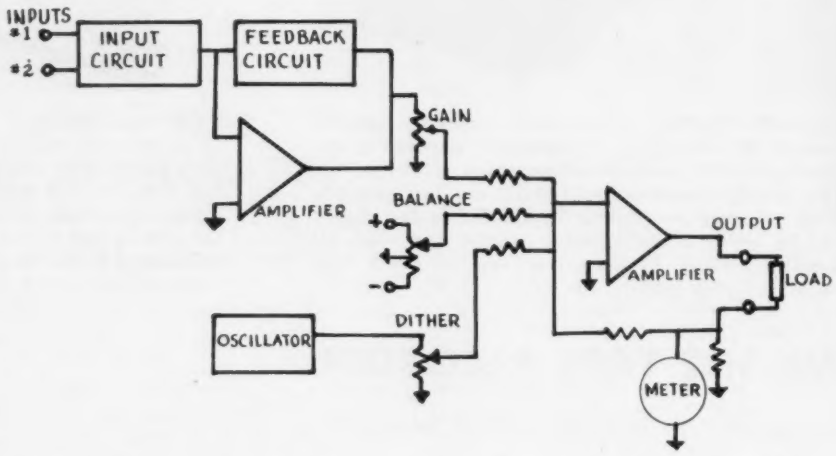
SERVO VALVE AMPLIFIER



Problems in developing an amplifier for servo valves may seem comparatively simple but for some reason good all around servo valve amplifiers are hard to find. Here are some of the requirements for servo valve amplifiers and how Thompson Controls Inc. of Birmingham, Alabama provided them in their Model T Amplifier.

1. High B+ voltage should be kept off servo valve coil. When the coil shorts to the valve body, that B+ can be a real surprise stinger. It can be fatal. In the Model-T, one end of the coil is separated from ground by a low resistance monitor resistor.

2. Output resistance of the amplifier should be very high to insure that the coil time constant is not a factor in the dynamic response of the servo valve. High output impedance also eliminates the affect of back e.m.f. in the torque motor. Current feedback is employed in the Model T to provide infinite output impedance.



3. It is convenient for the output current to be proportional to input voltage. The gain of servo valves is logically rated in terms of GPM of oil flow per milliampere of input current. The problem of determining system gain is simplified if the amplifier output current is independent of coil resistance. Current feedback in the Model T also makes the gain, in terms of output current to input voltage, independent of coil resistance.

4. Servo valves generally require a small high frequency dither signal. Dither tends to overcome static coulomb friction. Resolution of servo valves is improved by a factor of 5 or 10 by use of dither. Model T includes an oscillator to provide dither. Dither frequency can be changed by a simple circuit element replacement.

5. It is often worthwhile to have available a monitor signal proportional to output current. This monitor should be referenced to ground so that it can be easily applied to test equipment. Such a monitor signal is not readily available in most conventional servo amplifiers. Model T makes available an output monitor voltage referenced to ground and proportional to output current.

6. The front panel controls normally required are gain, balance, and dither. These controls should be independent. The adjustment of one should not affect either of the others. This is very important to the man who has to adjust these controls for a closed loop system. Gain control in the Model T affects the amplified signal ahead of the point where balance and dither are summed into the signal path.

7. It is often worthwhile to have a place to mount compensating networks for a closed loop system. The first stage of the Model T is a chopper stabilized dc amplifier connected as an operational amplifier. Input and feedback circuit boards are accessible for compensating a closed loop system.

8. Provision should be made for summing several input signals. Input signals for a closed loop might be, for example, a command signal, a rate feedback signal and a position feedback signal. In the Model T, many signals can be summed at the input circuit of the first stage operational amplifier.

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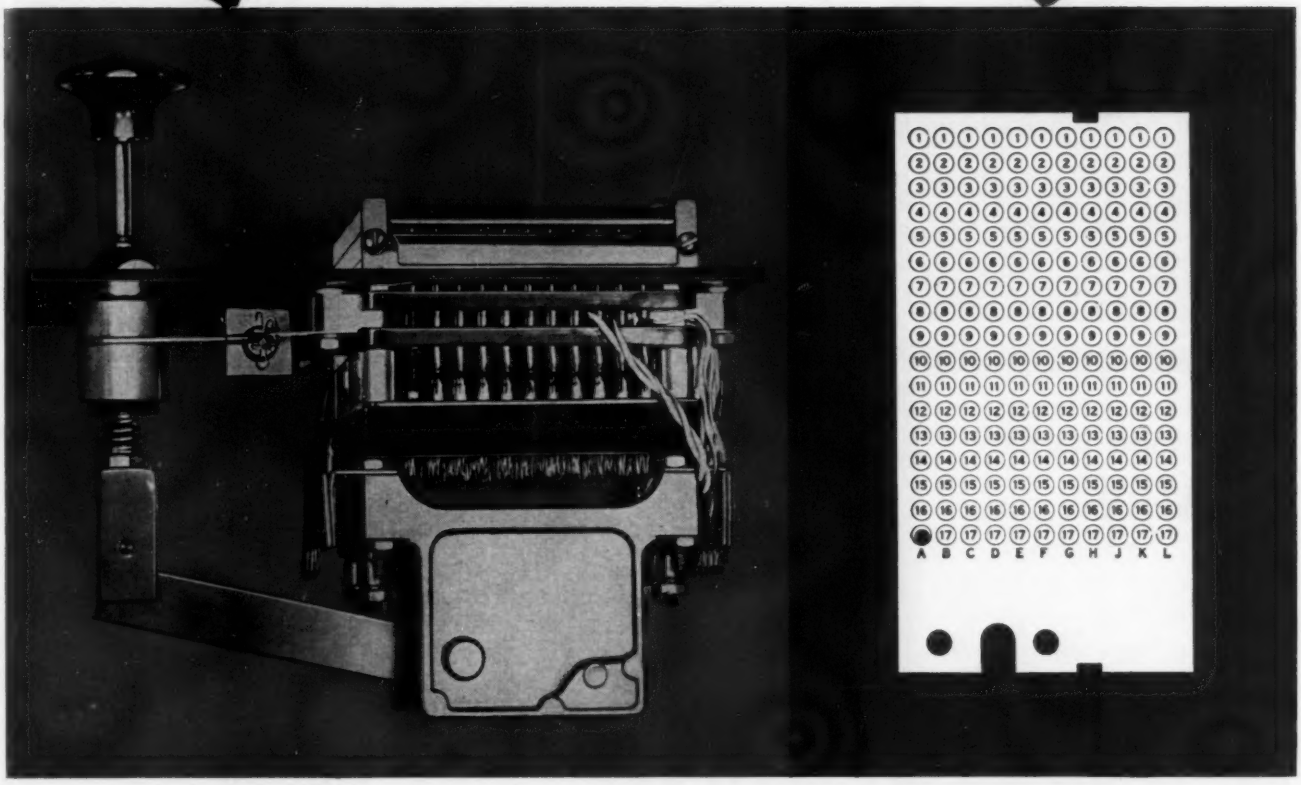
THIS SWITCH...and THIS CARD



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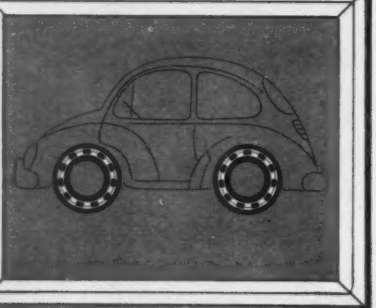
Thinking small?



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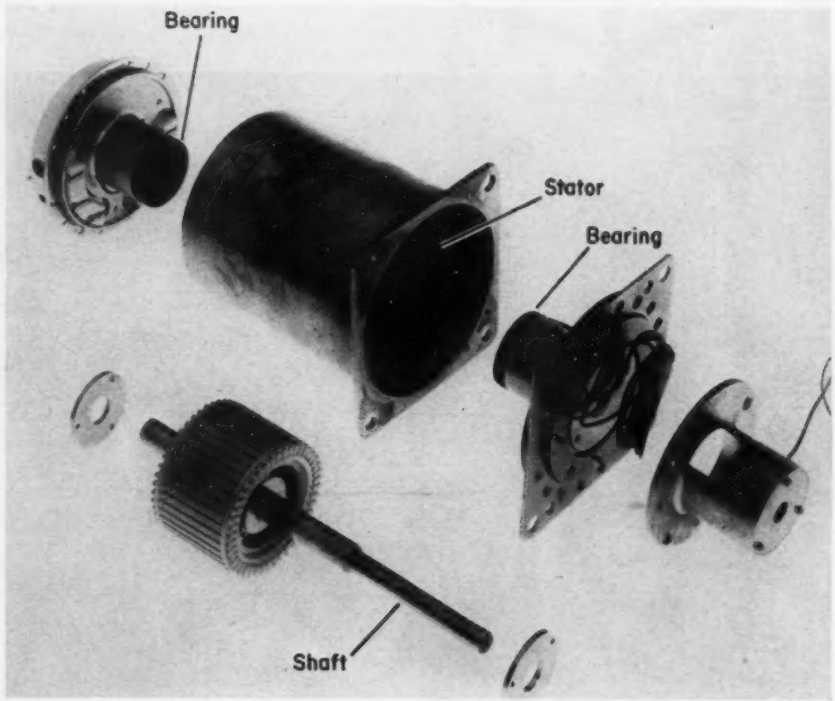

HIGH TEMPERATURE MOTORS

Three-Piece Graphite Bearing Solves Design Problems

In designing a 0.5 hp, alternating-current motor for use in aircrafts operating at altitudes to 80,000 feet and in ambient temperature to 600°F, AiResearch Mfg. Co., Div. of The Garrett Corp. had to find motor bearings capable of withstanding temperatures up to 870°F, with continuous-duty rating and under lack of external cooling and lubricants.

Using a three-piece configuration and carbon-graphite material, engineers at AiResearch came up with a bearing that gave the required long life under high radial load without lubricants. Graphitar 2490, a high temperature and oxidation-resistant grade of carbon-graphite, made by The United States Graphite Co., has a low coefficient of friction, high wear resistance, and good stability.

To overcome the relatively low tensile strength, the bearings were designed with unconventional mounting to obtain maximum benefit from the material's high compressive strength. Shrink-fitting the Graphitar parts in place keeps the bearings in constant compression. In addition to the three radial-segment configuration of each bearing, a length-to-width ratio of more than two-to-one was used to distribute the high radial load. Precision boring of the bearings was performed by first assembling the motor housing, end bells, and bearing segments. To eliminate galvanic action between the bearings and motor shaft, which was encountered during humidity tests, the shaft bearing surfaces were flame plated with aluminum oxide.

Motors successfully passed a tough series of special and standard military tests including di-electric, acceleration, shock, vibration, life, humidity, salt spray, and load tests. Since the final ambient temperature capabilities of the motor were unknown, a unit was run for two hours with bearing temperatures of 1100 degrees F., without adverse effects.

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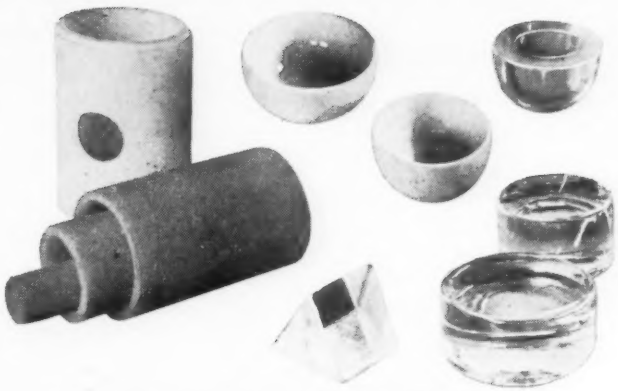

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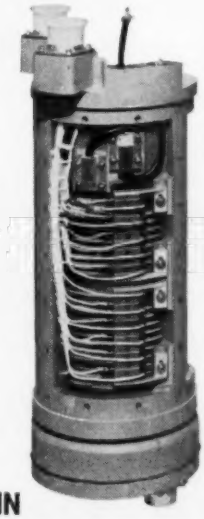

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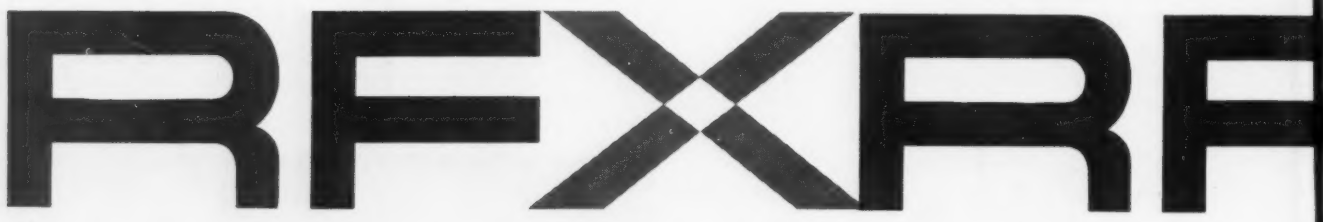

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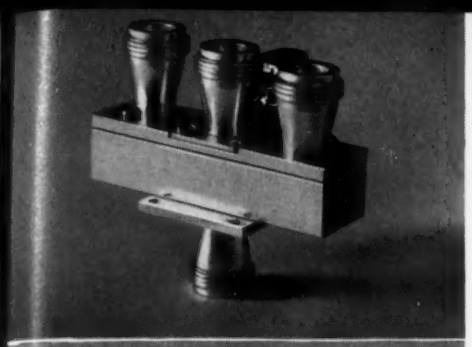

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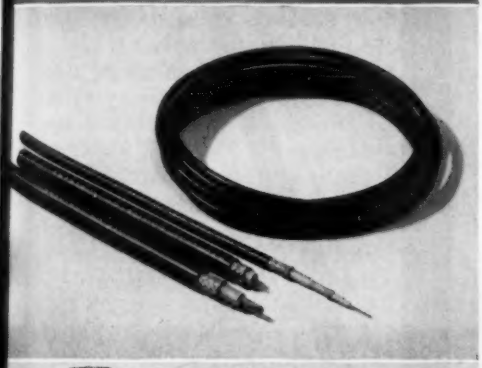

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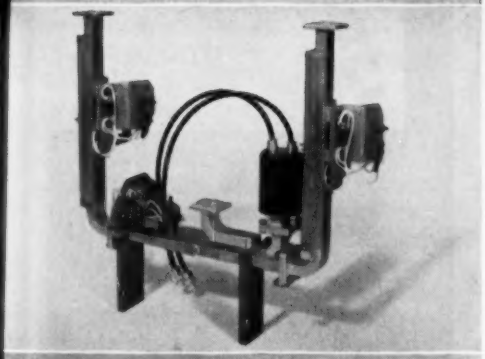

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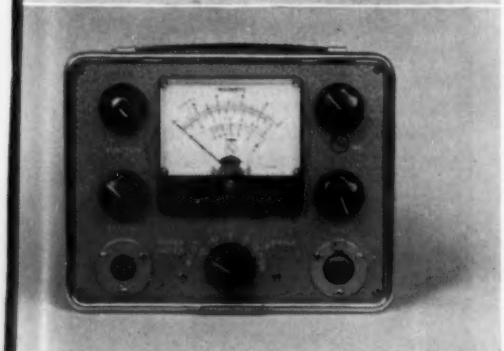

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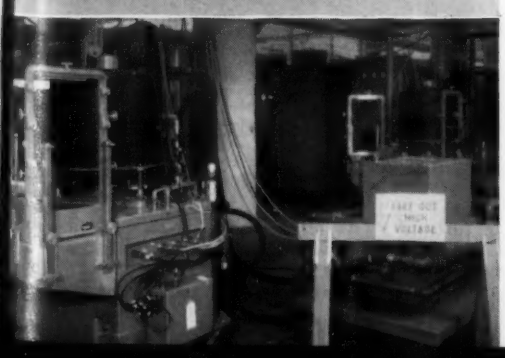

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BALL SCREWS

Successor to the Acme screw drive and preferred in many applications to hydraulic and pneumatic systems. Guaranteed 90% efficient in converting rotary twist to linear push (or vice versa). Employs a stream of precision balls and ground lead to eliminate drag and wear in delicate instruments, aircraft, machine tools, massive wind tunnel jacks, etc. For horizontal and vertical actions, indexing, inching and traversing. Consultation and engineering service available. Write for literature.

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Beaver Precision Products INC.
CLAWSON, MICH.

CIRCLE NO. 22 ON INQUIRY CARD

FLUID-SPHERE INERTIAL GYRO

Elimination of Spinning Wheel Reduces Drift and Cost

Inherent stability of fluid spinning inside a simply designed and produced rotor assembly guarantees a perfectly balanced and ultra-reliable gyro at very low cost. The spinning mass of liquid confined within a hollow sphere replaces the conventional rotating wheel. Quantities of the fluid sphere gyro developed by the Sperry Gyroscope Co. can be produced for sale at less than $2,000 per unit.

Designed for mass production, the two-axis SYG-2000 requires no precision parts or involved assembly techniques. It contains less than half the number of parts required by the best conventional inertial gyros.

Bearing wear or shifts in structural dimensions have only slight effect on the performance of the gyro. The company states it has an anisoelastic drift of less than 0.003 degrees/hr/g^2, and can be stored or operated at temperatures from minus 65 to plus 200 degrees F.

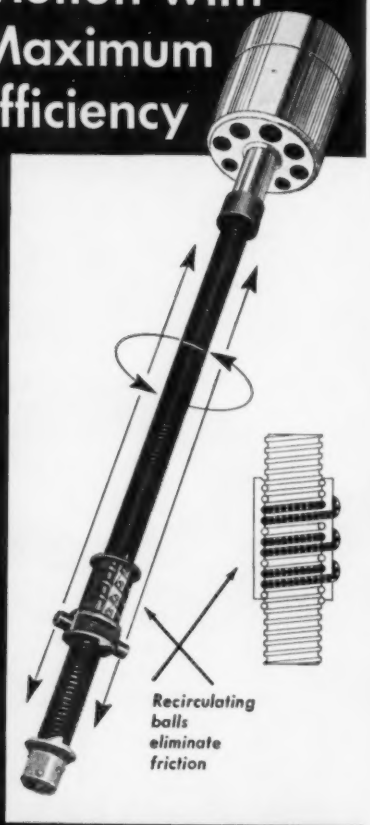
In operation, the fluid spins at approximately the same speed and around the same axis as the gyro rotor. Any angular movement of the rotor from this axis produces variations in pressure between the fluid and cavity wall. Pressure is sensed by a series of diaphragms buried in the rotor-cavity assembly and opened to the fluid through pickoff ports in the cavity wall.

Pressure variations force the diaphragms to oscillate at an amplitude proportional to the angular displacement between the rotor and fluid axes with a phase that indicates the axis about which the displacement occurs. The diaphragms act as elements of a miniature microphone, to convert pressure variations into electrical signals.

The SYG-2000 has been in development for over two years and is currently an applied research project of the Aeronautical Systems Division of the U.S. Air Force. Current production units are being manufactured by Sperry for a classified military project.

Write No. 293 in Box on Inquiry Card

How to Convert Rotary Electric Power to Linear Motion with Maximum Efficiency



Beaver Ball Screws offer better than 90% efficiency and compactness that can be matched by no other converting media. Not always — but generally — ball screws are preferred to hydraulics and pneumatics where system stiffness, freedom from backlash and surge are essential for extreme accurate control of positioning. Reliability, long life and control of movement under load fluctuations are other dominant ball screw characteristics.

Our engineers will be glad to review your application with you.

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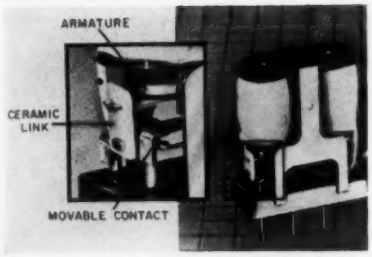

MAGNETIC LATCHING RELAY

Push-Pull Action Provides Secure Contact Mating

Electro-magnetic forces, in a new magnetic latching relay, are properly matched to the armature and contact load to eliminate "hang-up" and assure positive follow-through and snap-action closure on low power pulses. Armature "carries" the movable contact through a ceramic link. This push-pull action with no spring bias provides secure contact mating in either pole position.

General Electric engineers state that pull force is well in excess of load during the entire transfer process, even at minimum operating power of 50 milliwatts for single coil types and 75 milliwatts for dual coil construction. High holding forces, augmented by a permanent magnet, provide high vibration and shock immunity. Tests show no contact opening under 30 g vibration to 3000 cps or 100 g shock. All relays are designed for either power or low level switching. Ambient operating temperature range is −65° to +125°C.

Each hermetically-sealed relay is of all-welded high reliability construction. Possibility of flux contamination or solder spatter is eliminated, since no solder or flux is used to join the header to the enclosure or the contacts and coils to the pins. Newly-developed inert arc-welding closure process hermetically seals the nitrogen-filled enclosure to the header.

Series AM relays are rated at 5 millisecond maximum operating time, including bounce time, at twice maximum pick-up current. Coil resistance is 0.050 ohms maximum before use; no more than double that after 100,000 operations. Bounce time is 1 millisecond maximum. Furnished in the standard grid spaced configuration with terminations on 0.2-in. and 0.1-in. centers, units are available from General Electric's Specialty Control Dept., Waynesboro, Va.

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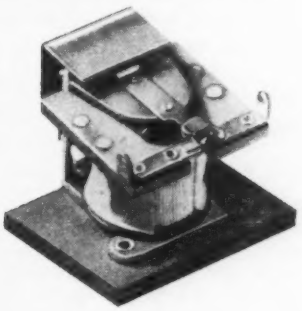
let's go halfies!

Looking for a midget relay for a man-sized job? Let's go halfies! You take our new economical Series 5300 relay—it occupies less than half the space of any comparable electromagnetic device for general purpose applications! We take the pleasure in seeing you use your new-found space to much better advantage!



CDE SERIES 5300 RELAY, ACTUAL SIZE

Dimensions: Approx. 1 cu. inch volume!

Weight: 1¼ ounces max.!

Electrical: Rated at 115 VAC resistive, 3 amps max. 1 Form C contacts (SPDT operation), require only 2.5 VA to operate. Maximum AC coil voltage is 220 V, 60 cycle.

Environmental: Withstands 95% humidity, 10 g's shock or vibration at 5 to 55 cps operating, 50 g's non-operating. Ambient temperature range from −65C to +70C.

Applications: Communications and entertainment equipment; specialized and remote control switching.

Delivery: 1 to 4 weeks, depending on quantity.

Terminals and contacts: Supplied with a cover and lugs and/or leads for coil terminals. Contacts are silver, palladium, coin silver or any other required material.

Cornell-Dubilier produces the following complete lines of relays for commercial, industrial and military applications: high-reliability telephone-type relays, miniature semi-sensitive general-purpose relays, intermediate multi-pole general-purpose relays, miniature heavy-duty power contactors, deliberately desensitized differential relays for electro-mechanical discrimination, solenoids, hundreds of special types to suit your individual needs.

CDE CORNELL-DUBILIER

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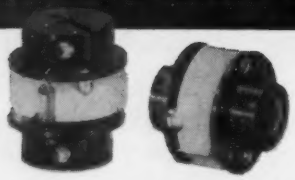
CIRCLE NO. 24 ON INQUIRY CARD

TIC

MINIATURE FLEXIBLE COUPLINGS

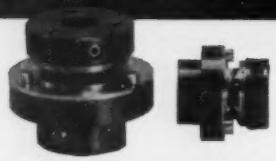


FEATURE • No Backlash • Compactness and Lightweight • Accommodate both lateral and angular misalignment • Choice of types offer clamping or set-screw hubs

Type MPC-1 consists of two flanged aluminum hubs and nylon or Delrin discs with V-grooves that are displaced 90° with each other. Discs are fastened with stainless steel springs loading ball pivots against V-grooves. Dimensions ⅞ x ⅞ in.
Type MPC-2 has two cylindrical aluminum hubs, each with two ball pivots attached. Hubs are attached to a pair of flexible phosphor bronze discs which hold and load the ball pivots. Dimensions ¾ x ½ in. Both types have range of bores to accept shafts from .120″ to .250″ and meet MIL-E-4970 and withstand −80° to 200°F and shock to 100 G.

TIC

ADJUSTABLE SLIP CLUTCHES



FEATURE • Adjustment over a wide torque range • Compactness and lightweight

Type ASC-1 is ⅞ x 1″
Type ASC-2 Miniature is ⅝″ x ⅝″
Both are constructed of aluminum hubs, Delrin® on stainless steel clutch plates and stainless steel hardware. These rugged, high performance clutches are friction units to protect components against excessive or inertia shock loads. Range of bores to accept shafts from .120″ to .250″. These clutches meet MIL-E-4970 specs.
For details on couplings or clutches write

® DUPONT T.M.

TIC

For further information write
TECHNOLOGY INSTRUMENT CORP.
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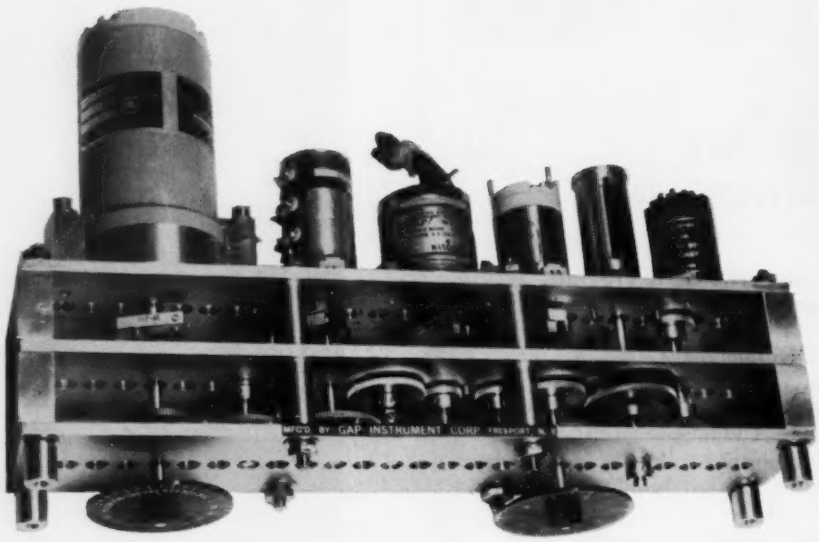
CIRCLE NO. 25 ON INQUIRY CARD

SYSTEMS DESIGN



STRAIGHT-LINE GEAR SYSTEM

A fast, flexible, and economical way to build a wide variety of simple and moderately complex gear trains is illustrated in this photograph of a straight-line gear train system by Gap Instrument Corp., Newtown, Conn.

The framework of a typical straight-line assembly is built up of 2 or 3 highly precise jig bored plates and sets of spacer blocks and posts. Spacers and posts are selected to accommodate the number of gears and couplings to go between the plates.

Stocked plates are all 2 3/16″ wide and come in various lengths up to 11⅝″. The single line of equally spaced gear centers is held to noncumulative tolerance of plus or minus .0002″ and a diameter tolerance of plus .0002 minus .0000″.

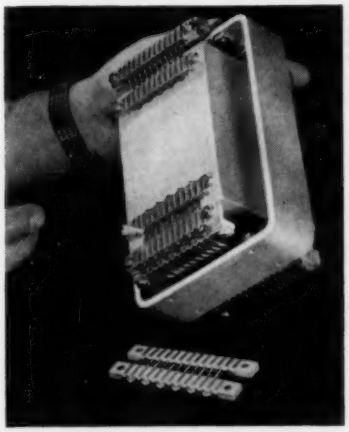
The gear train itself is built up of parts comprising the Gap Servo Construction System which includes stocked gears, ball bearings, shafts, dials, index markers, handwheels, adjustable mechanical stops, adjustable electrical stops, component adapters, component clamps, couplings and terminal blocks. A few motors, synchros and transistorized amplifiers are also stocked. Components of size 23 and smaller are readily accommodated.

Included in the typical unit shown are: a Mark 14 servo motor geared 22:1 to a 36X size 10 mechanical stop through an adjustable slip clutch, a 36X size 11 synchro and dial, a 10X size 15 synchro, a 1X size 10 potentiometer and dial, and a 1X size 23 resolver. Construction is such that the synchros or potentiometers may be removed from the unit without destroying gear train synchronism. Provision is made for mounting to the back of a panel or on a horizontal base. This particular unit is 2¼″ high by 11½″ long and 7¾″ deep. Backlash at the 1X potentiometer is about 3 seconds with motor locked and can be reduced with anti-backlash devises. Units constructed with the straight-line system very closely approximate a production unit. Only the few unused jig bored holes need to be deleted. The improved one piece component clamp is fastened directly into tapped holes.

Gap builds the complete gear train and assembles with it customer-furnished rotating electrical components. Dust covers are optional. Gap will engineer these gear trains directly from a schematic.

Delivery of a completely assembled unit normally can be made within 2 weeks after receipt of order or 1 week after receipt of customer furnished rotating components, whichever is later.

Write No. 273 in Box on Inquiry Card



SHOCK AND VIBRATION ISOLATOR BASED ON SEISMIC MOTION

The principle of seismic motion has been applied in the design of a Cable Isolator System which consists of prestressed twisted strands of cable mounted between two steel retainers. Aeroflex Labs., Inc., reports the following outstanding characteristics of their shock and vibration isolation system as: protection of supported mass in all altitudes from shock, vibration and random noises — even in combination with high steady-state G loads; isolation in all three planes; stability and repeatability of performance; never bottoms — even under severe overloads; adjustability in the field for optimum detuning; minimum space requirements and versatile attachment; universally applicable to severe loads and environments; custom results with standard hardware; rugged, all-metal construction, unaffected by temperatures from —100F to —500F; meets MIL-E-5272C and exceeds performance requirements of MIL-C-172.

Individual isolators can be joined and mounted together by means of L-type brackets to form a complete isolating system for application on electronic components, instruments and mechanical gear requiring shock and vibration control during shipment, handling and use. The Cable Isolator provides anti-resonance features not found in other shock mount systems, according to the company.

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WORTH FILING

Magnetic Pickups

Nomograph on magnetic pickups enables users to quickly calculate: gear sizes needed for the required voltage frequency to be generated by the pickup; gear surface speeds from rpm; expected voltages and/or frequencies.

Source: Electro Prods. Labs., Chicago, Ill.

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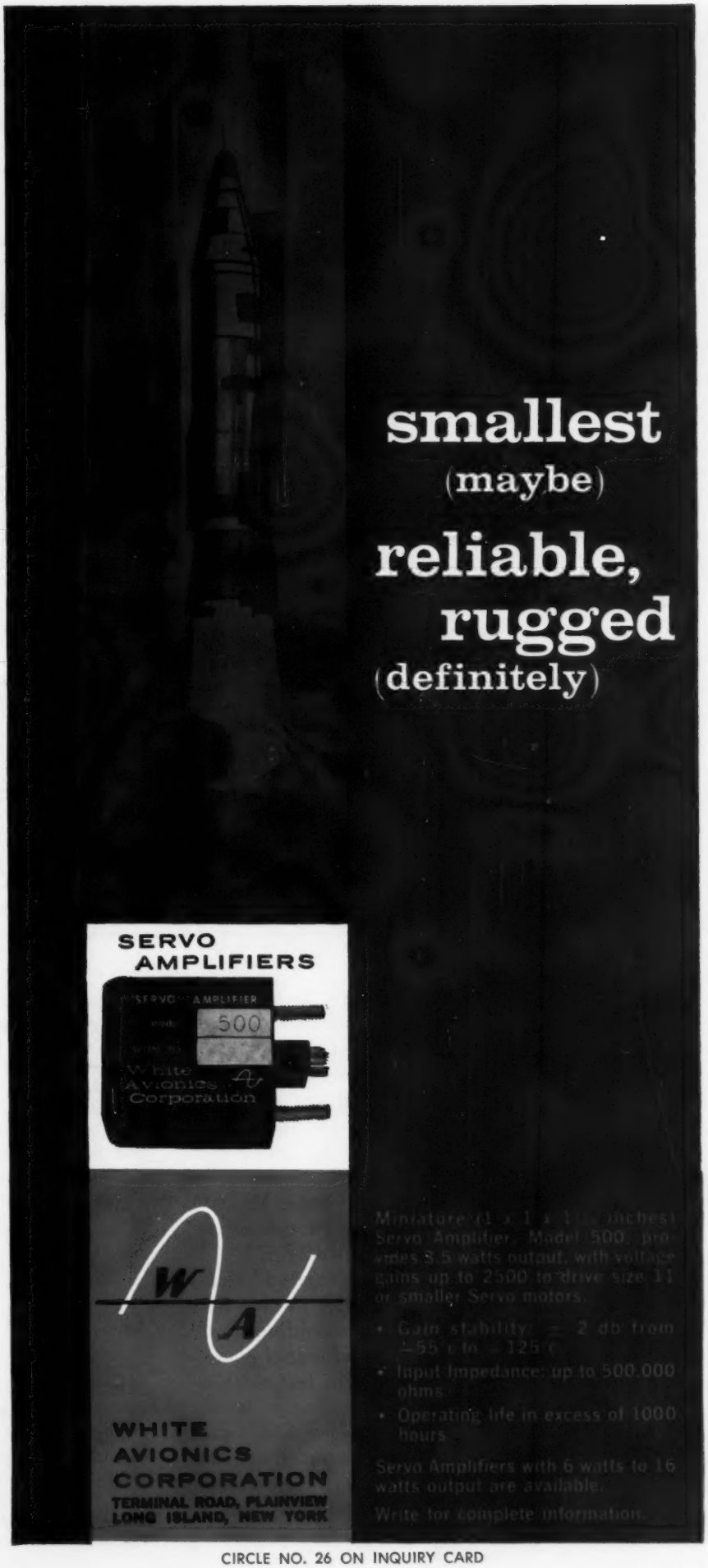
smallest
(maybe)
reliable,
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SERVO AMPLIFIERS
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White Avionics Corporation
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Miniature (1 x 1 x 1 — inches) Servo Amplifier, Model 500, provides 3.5 watts output, with voltage gains up to 2500 to drive size 11 or smaller Servo motors.
• Gain stability: ± 2 db from —55 c to +125 c
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Servo Amplifiers with 6 watts to 16 watts output are available.
Write for complete information.

CIRCLE NO. 26 ON INQUIRY CARD

CALCULATING NO LOAD OUTPUT OF DRAG CUP TACHOMETERS

P. H. Trickey, Manager Motor Engineering Dept., Wright Machinery Co., Div. Sperry Rand

Not long after the two phase induction motor was invented it was discovered that after the motor had obtained running speed, it would continue to run even though the second phase was disconnected from the line. It was only necessary to connect the second phase for starting. In using such "single phase" motors another interesting discovery was made. The "back e.m.f." or induced voltage was still present in the second phase. This voltage was practically 90° out of phase with the main line voltage. One of the first applications, to which it was put, was in the use of a large single phase motor running idle in a locomotive with power taken from the second phase to feed phase two of the driving motors. The single phase machine used in this fashion is called a phase converter.

Later on, engineers found that if the rotor resistance was increased considerably, the phase two voltage became proportional to the speed and more nearly in phase with the line voltage. Thus the machine could be used as a tachometer generator.

"Phase converter" tachometers, at first, were simply little single phase motors with high resistance squirrel cage rotors. After a while, it was found that eliminating the slots and putting a sleeve or cup over unslotted rotor laminations reduced the slot ripple or "slot lock" effect. Somewhat later, it was discovered that lower inertia could be obtained by letting the secondary iron laminations stand still, leaving only the "drag cup" attached to the shaft, giving the additional advantage of having a fixed air gap at all times and not variable as the shaft rotated.

Although many refinements in windings and techniques of manufacture have evolved over the last few years, the basic machine is still of the rotating "drag cup" design. Sometimes both input and output phases are in the outer member as in the very first designs; or both windings are on the inner member or "stud"; or frequently, the windings are arranged with input on the outer member and output on the inner member or vice versa. A method for calculating performance with any of these arrangements, before the unit is actually built, is presented here.

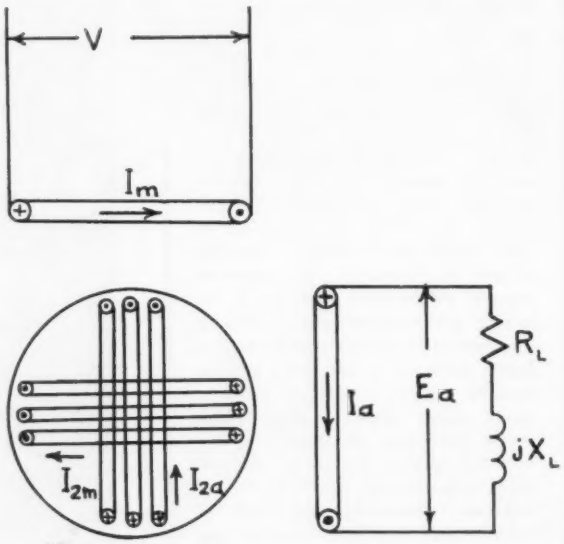

Fig 1 Schematic diagram of ac drag cup tachometer

The single phase ac drag cup tachometer generator is simply the big power phase converter reduced to a very small size with the rotor resistance increased to such a large value that linearity and small phase shift are obtained. Figure 1 shows the schematic diagram of this machine.

By summing up the voltages in each of the circuits the four basic current equations are obtained.

$$I_m(r_1 + X_1) + jI_mXM - jI_{2m}X_M = V$$

$$I_{2m}(r_2 + jX_2) + jI_{2m}X_M - jI_mX_M + S(aI_a)X_{Ma}/a^2 - SI_{2a}(X_{Ma} + X_{2a})/a = 0$$

$$I_a[(r_{1a} + R_L) + (X_{1a} + X_L)] + jI_aX_{Ma} - jI_{2a}X_{Ma} = 0$$

$$I_{2a}(r_{2a} + jX_{2a}) + jI_{2a}X_{Ma} - jI_aX_{Ma} - SaI_mX_M + SaI_{2m}(X_M + X_2) = 0$$

It is possible to solve these equations and be able to calculate the complete performance of this machine under any condition of output loading. However, in many cases it is sufficient to calculate the no load or open circuit output voltage and make approximations for the effect of load current. The infinite impedance, zero load current assumption simplifies the solution and the final current equations are much less cumbersome.

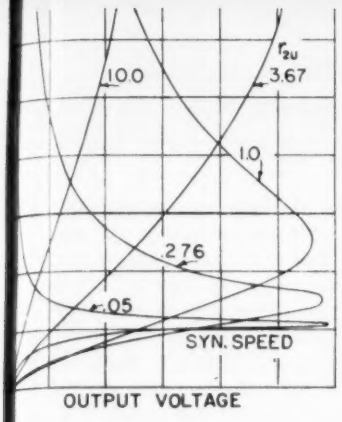

Fig 2 Effect of rotor resistance on open circuit output voltage

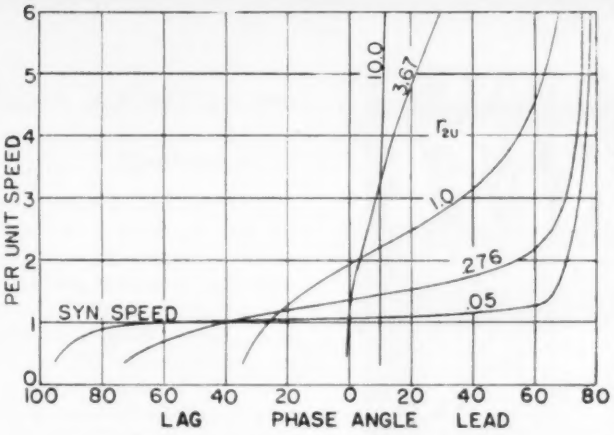

Fig 3 Effect of cup resistance on the output phase angle of typical ac phase converter tachometer

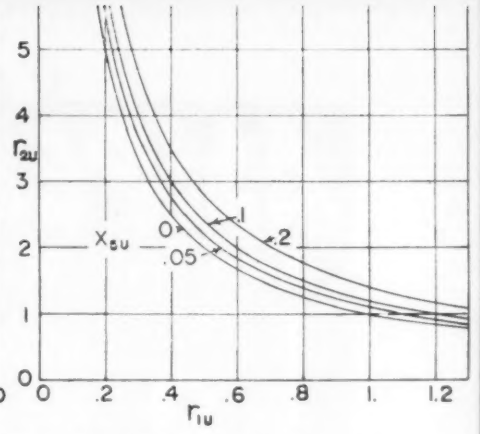

Fig 4 Relationship between r_{1u} and r_{2u} to give zero phase shift at no load, synchronous speed and $X_s = 0$. In this case $X_{su} = X_1/X_{01}$ and $1/r_{1u}\ \{(X_{01}/X_{02}) + X_{su}\} = 1/r_{1u}\ \{1 + (2X_1/X_{02})\}$

$$I_m = \frac{G_4 + G_5(1 - S^2) + I'_{fe}U + j[-G_{11} + I'_{fe}W]}{U + jW}$$

$$I_{2m} = \frac{0 + G_3(1 - S^2) + j(G_1 + 0)}{U + jW}$$

$$I_a = 0;\ I_{2a} = \frac{G_2 S + j0}{U + jW}$$

$$U = G_{19} + G_{17}(1 - S^2) \quad \text{and} \quad W = G_{18} + G_{16}(1 - S^2)$$

$$E_{aNL} = jI_{2a}a^2X_{02}K''_p = Sa^2X_{02}K''_p\left(\frac{jG_2}{U + jW}\right)\left(\frac{U - jW}{U - jW}\right)$$

$$E_{aNL} = SaX_{02}K''_r\left(\frac{(-W - jU)}{U^2 + W^2}\right)$$

The phase angle of the no load voltage is:

$$\theta_a = \tan^{-1}\left(\frac{-U}{-W}\right)$$

The "G" constants are: $G_1 = -K''_p$, $G_2 = -K''_p/a$, $G_3 = K''_p/r_{2u}$, $G_4 = -r_{2u}$, $G_5 = 1/r_{2u}$, $G_{11} = 2.0$, $G_{16} = \left(\frac{1}{i''_m}\right)(X_{su}/r_{2u})$, $G_{17} = \left(\frac{1}{i''_m}\right)(r_{1u}/r_{2u})$, $G_{18} = \frac{1}{i''_m}\left[-(2r_{1u} + r_{2u})\frac{X_{01}}{X_{02}}\right]$

$$G_{19} = \frac{1}{i''_m}\left[X_{su} + \frac{X_{01}}{X_{02}} - r_{1u}r_{2u}\right]$$

These equations are most easily used when arranged in proper sequence for a minimum of slide rule or computer operations such as shown in the worked example of Table I.

SINGLE PHASE MOTOR

Under the condition of no load, the tachometer actually becomes a single phase motor with an abnormally high rotor resistance. Thus, it is possible to use the calculation operations in Table I instead of classic conventional methods where the usual simplified methods are not sufficiently accurate. This would apply not only to cases where X_1 is not equal to X_s but most particularly to cases where rotor resistance is very high as in servo motors with the control phase open. This problem sometimes occurs in determining whether a servo motor will "single phase" or not, that is,

TABLE I Example Calculation

1.	$X_1 = X_s$			31.	$G_9 = (10)/(25)$	0.2725	61.	$N_{1h} = (63) - (64)$	−3.67
2.		X_1	4.53	32.	$G_8 = 1/(25)$	0.2725	62.	$(12) \times U$	.0001
3.		X_s	0	33.	$G_{18} = (28)/(25)$	0.0187	63.	$N'_{1h} = (65) + (66)$	−3.67
4.		X_M	65.9	34.	$2\ (26)$	0.618	64.	$(12) \times W$	−.24
5.	X_o	$X_{os} = X_M + X_s$	65.9	35.	$(25)\ (6)/(5)$	3.915	65.	$N_{1v} = -2.0$	−2.00
6.	$X_{o1} = X_o$	$X_{o1} = X_M + X_1$	70.43	36.	$(34) + (35)$	4.533	66.	$N'_{1v} = (68) + (69)$	−2.24
7.		$(X_M/X_{os})\ X_s$	0	37.	$G_{15} = -(36)$	−4.53	67.	$N_1 = [(67)^2 + (70)^2]^{1/2}$	4.3
8.	X	$X_1 + (X_M/X_{os})\ X_s$	4.53	38.	$(6)/(5)$	1.069	68.	$N_{2h} = (53)\ G_2$	0
9.	$X_o - X$	----	----	39.	(28)	0.0688	69.	$N_{2v} = G_1$	−1.0
10.	$K_p = [(9)/(5)]^{1/2}$	$K''_p = X_M/X_{o1}$	1.00	40.	$(38) + (39)$	1.138	70.	$N_2 = [(72)^2 + (73)^2]^{1/2}$	1.0
11.	F_{rm} @ $VK\phi$ Volts		10.25	41.	$(26)\ (25)$	1.134	71.	$N_{1h} = S\ G_9$	−0.576
12.	$I_{fe} = (11)/(VK\phi)$		0.091	42.	$G_{16} = (40) - (41)$	0.0036	72.	$N_1 = [(75)^2]^{1/2}$	0.576
13.	$r'_{fe} = VK\phi/I_{fe}$		1237	43.	$G_{16} = (33)/(17)$	0.0109	73.	$I_1 = (71)/\Delta$	1.63
14.	$r_{2\ hot}$		20.76	44.	$G_{17} = (27)/(17)$	0.0491	74.	$I_{2m} = (74)/\Delta$	0.378
15.	$(13) + (14)$		1257.8	45.	$G_{18} = (37)/(17)$	−2.64	75.	$I_{2a} = (76)/\Delta$	0.218
16.	$K_{fe} = (13)/(15)$		0.983	46.	$G_{19} = (42)/(17)$	0.0021	76.	$(5)\ (10)\ (18)$	114.3
17.	$i''_m = V\ (16)/(5)$		1.714	47.	$S = RPM/N_s$	1.0	77.	$E_a = (79)\ (80)\ (18)$	43.3
18.	$a = (CK_{wa})/(CK_{wm})$		1.732	48.	S^2	1.0	78.	$\theta_a = \tan^{-1}(-U/-W)$	0
19.	$(a)^2$		3.0	49.	$1 - S^2$	0	79.	$-(75)\ (65)$	−2.12
20.	F_{cc}		9.25	50.	G_{19}	0.0021	80.	$I_1^2\ r_1$	55.0
21.	$F + W$		5.0	51.	$(53) \times G_{17}$	0	81.	$I^2_{2m}\ r_2$	34.5
22.	$(20) + (21)$		14.25	52.	$U = (54) + (55)$	0.0021	82.	$I^2_{2a}\ r_2\ a^2$	34.5
23.	$r_{2\ hot}\ (1.153)$		242.	53.	G_{18}	−2.64	83.	F_{cm}	10.25
24.	$r_{1e\ hot}\ (1.153)$		10.32	54.	$(53) \times G_{18}$	0	84.	(84) thru (87)	134.25
25.	$r_{2u} = (23)/(5)$		3.67	55.	$W = (57) + (58)$	−2.64	85.	$(83)\ (80)\ S/(61)$	−34.6
26.	$r_{1u} = (14)\ (16)/(5)$		0.309	56.	$\Delta = [(U)^2 + (W)^2]^{1/2}$	2.64	86.	$Inp. = (88) + (89)$	99.65
27.	$(26)/(25) = r_{1u}/r_{2u}$		0.0842	57.	Δ^2	7.00	87.	$(22) \times S^2$	14.25
28.	$(8)/(5) = X_{su}$		0.0688	58.	$\theta\ \Delta = \tan^{-1} W/U$	−90	88.	$Output = (89) - (91)$	−48.85
29.	$G_2 = -(10) = -K''_p$		−1.00	59.	$(53)/(25)$	0	89.	$RPM = S\ N_s$	3600
30.	$G_3 = -(10)/(18)$		−0.576	60.	(25)	3.67	90.	$T = 112.7(92)/(93)$	−1.53

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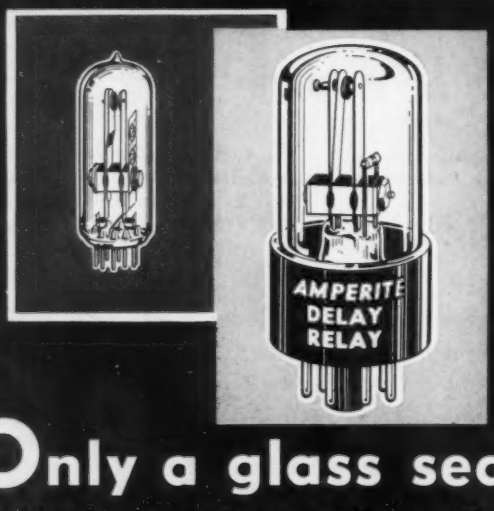

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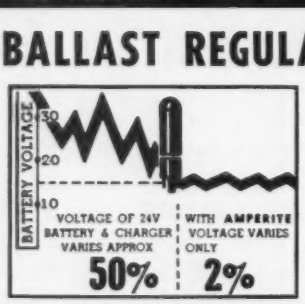

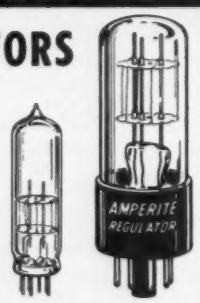

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continue to run with the control phase open.

ROTOR RESISTANCE

Perhaps the most important parameter in the equations for this machine is the ratio of rotor resistance to open circuit reactance $r_{2u} = r_2/X_{o2}$. For instance in the normal induction motor or power converter, r_{2u} is very low, from about 0.02 to about 0.10. In this range, the machine acts as an actual "phase converter" and the output voltage will be approximately 90° from the input voltage. However, when the machine is designed for tachometer operation, r_{2u} is made to be from 1.00 to 5.00 and the phase angle then increases to lie approximately in-phase with the applied input voltage. The linearity of the output voltage with respect to speed also improves greatly. Figure 2 shows the effect of r_{2u} on the shape of the voltage speed curve. Figure 3 shows the effect of r_{2u} on the phase angle of the output voltage with change in speed.

PHASE SHIFT

Since the drag cup or phase converter tachometer is

TABLE II
DEFINITION OF SYMBOLS

Symbols correspond in general to the AIEE Proposed Standard for Induction Motor Letter Symbols. It has been necessary to modify slightly in some cases and add to those given in the Standard.

r_1	resistance of main winding in ohms
r_{1a}	resistance of auxiliary or output winding in ohms
X_1	primary leakage reactance of main winding in ohms
X_2	secondary leakage reactance referred to primary in ohms
X	"Ideal" short-circuit reactance $X_1 + X_2\,(X_M/X_M+X_2)$
X_M	apparent magnetizing reactance due to space fundamental of the mutual air gap flux in ohms
X_{o1}	total primary (or "open circuit") reactance $X_1 + X_M$
X_{o2}	total secondary reactance referred to primary $X_2 + X_M$
K'_p	$X_M/(X_M + X_1) = X_M/X_{o1}$
K''_p	$X_M/(X_M + X_2) = X_M/X_{o2} = AIEE$ "K".
K''_r	$(K''_p)^2$
R_L	load resistance in ohms
X_L	load reactance in ohms
F_{em}	iron loss in stationary iron of main phase in watts
F_{ec}	iron loss in stationary parts of auxiliary phase (cross-field) and any odd frequency or pulsation iron loss in watts
$F+W$	friction and windage losses in watts
$K\phi$	flux reduction factor due to primary IR drop
S	per unit speed = speed/synchronous speed
r_{1u}	r_1/X_{o2}, $r_{2u} = r_2/X_{o2}$
r_{2u}	$(r_{1a} + R_L)/a^2X_{o2}$
V	input volts
i''_m	V/X_{o2}
a	Effective Output Winding Turns / Effective Input Winding Turns
X_{1u}	X/X_{o2}

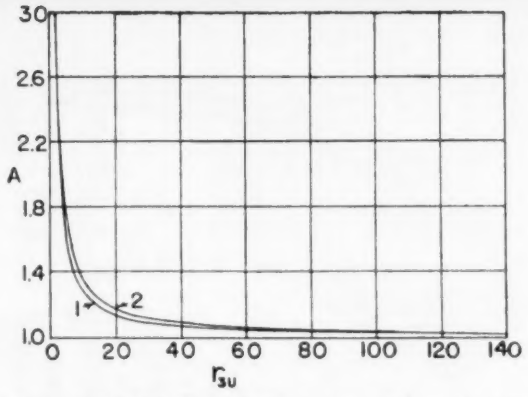

Fig 5 Relationship between r_{1u}, r_{2u} and r_{3u} to give zero phase shift at synchronous speed with:
$r_{1u} = 1/r_{2u}\{(X_{01}/X_{02}) + X_{3u}\}A$
$r_{3u} = (r_{1u} + r_L)/(a^2X_{02})$
(1)$r_{2u} = 2.0$, $X_3 = 0$, $X_1/X_{02} = 0.1$
(2)$r_{2u} = 3.0$, $X_3 = 0$, $X_1/X_{02} = 0.1$

used in systems where a low phase angle or shift is important, it is desirable to consider the proportions which affect phase shift under certain conditions.

No Load Phase Shift:

$$\theta_a = \tan^{-1}\frac{r_{1u}r_{2u} - [X_{5u} + (X_{01}/X_{02})] - (r_{1u}/r_{2u})(1 - S^2)}{[2r_{1u} + r_{2u}(X_{01}/X_{02})] - (X_{5u}/r_{2u})(1 - S^2)}$$

No Load Phase Shift at Synchronous Speed:

$$\theta_a = \tan^{-1}\frac{r_{1u}r_{2u} - [X_{5u} + (X_{01}/X_{02})]}{2r_{1u} + r_{2u}(X_{01}/X_{02})}$$

Zero Phase Shift at No Load, Any Speed:

$$r_{1u}r_{2u} = (X_{01}/X_{02}) + X_{5u} + (r_{1u}/r_{2u})(1 - S^2)$$

Zero Phase Shift at No Load, Any Speed When $X_{3u} = 0$:

$$r_{1u}r_{2u} = 1.0 + 2X_{5u}(r_{1u}/r_{2u})(1 - S^2)$$

Zero Phase Shift at No Load Synchronous Speed:

$$r_{1u}r_{2u} = (X_{01}/X_{02}) + X_{5u}$$

(Figure 4 illustrates this relationship in the common special case of $X_3 = 0$)

Zero Phase Shift at No Load Synchronous Speed, $X_{3u} = 0$:

$$r_{1u}r_{2u} = 1 + 2X_{5u} = 1 + 2(X_1/X_{02})$$

The above equations all point out that, in general, to achieve zero phase shift, the product r_{1u} r_{2u} must be slightly above 1.0. If the speed is below synchronism this ratio must be somewhat greater.

Although this article considers mainly the case of no load current, the effect of resistive load on the condition to give zero phase shift at synchronous (Fig 5 illustrates this relationship) is:

$$r_{1u} = \frac{A}{B} \text{ where } A = \frac{1 + (X_{01}/X_{02})^2B}{1 - (1/r_{3u})(1/B)}$$

$$B = \frac{r_{2u}}{(X_{01}/X_{02}) + X_{5u}}$$

INITIAL VOLTAGE GRADIENT, NO LOAD

It is desirable to know what initial voltage gradient or volts per 1000 rpm can be expected under various conditions. Assuming the case of no load, this gradient is:

$$\frac{E_{aNL}}{S} = VK_r'' a \frac{X_{02}}{X_{01}} \frac{1}{r_{2u}} A$$

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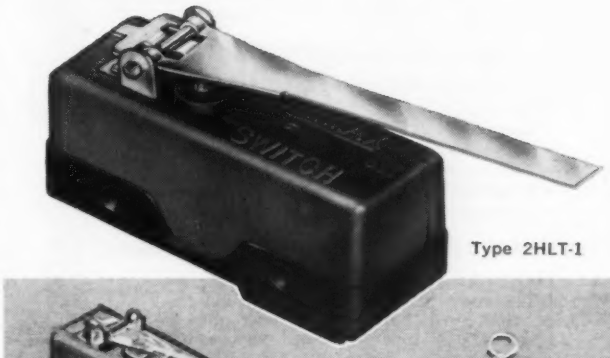

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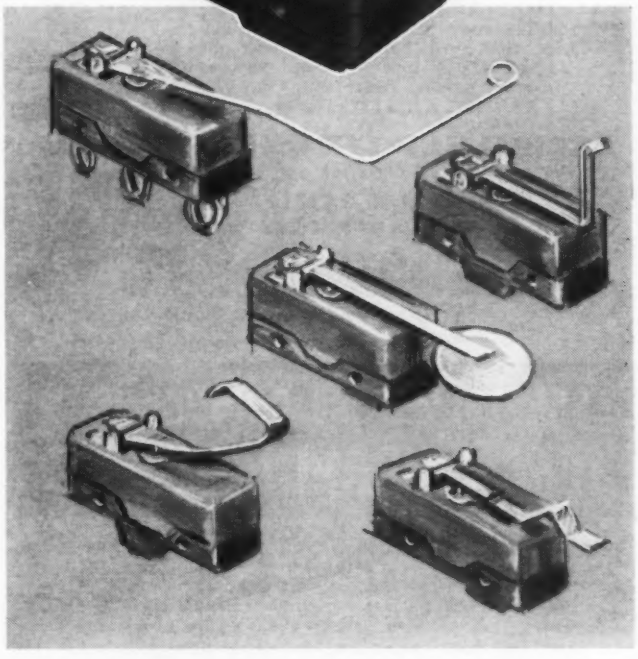

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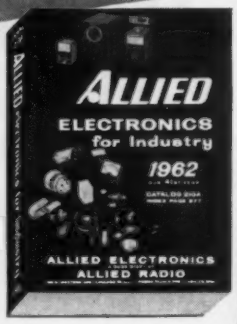

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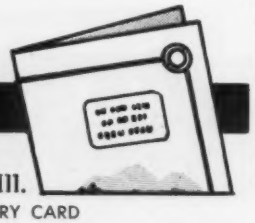

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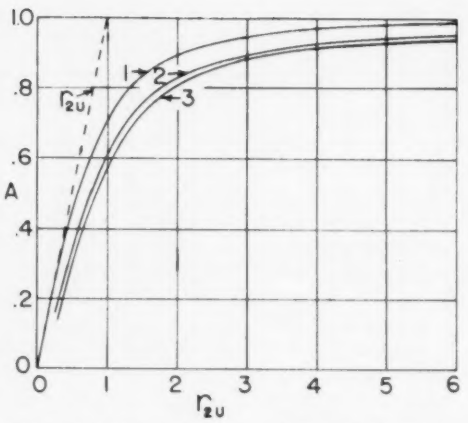

Fig 6 Initial voltage gradient of drag cup tachometer at no load

$E_{ANL}/S = VaK''_r\,(1/r_{1u})\;(X_{02}/X_{01})A,$

$r_{2u} = r_{2u}/X_{02}$

$(1) r_{1u} = 0, X_2 = 0, (X_1/X_{01}) = .1, X_{02}/X_{01} = .9$

$(2) r_{1u} = .2, X_2 = 0, (X_1/X_{01}) = .2, X_{02}/X_{01} = .8$

$(3) r_{1u} = .3, X_2 = 0, (X_1/X_{02}) = .3, X_{02}/X_{01} = .7$

$Volt/1000\ rpm = (E_{ANL}/S)\,(1000/Syn.\ Speed)$

$$\text{Where } A = \frac{1}{\sqrt{\left[\frac{1+(X/X_{01})}{r_{2u}} - r_{1u}\frac{X_{02}}{X_{01}}\left(1-\frac{1}{r_{2u}^2}\right)\right]^2 + \left[-1-2\frac{r_{1u}}{r_{2u}}\frac{X_{02}}{X_{01}} + \frac{1}{r_{2u}^2}\frac{X}{X_{01}}\right]^2}}$$

It can be seen from Fig 6 that for the large values of r_{2u} such as 2.0 and above, commonly found in drag cup tachometers, the voltage gradient is almost inversely proportional to r_{2u}. Thus the voltage gradient decreases directly as the cup resistance and the air gap increase.

LINEARITY

As seen in Fig 2, the speed voltage curve, for machines with high rotor resistance, bends to the left as the speed is increased, giving a voltage less than proportional to speed. If the difference between actual and ideal voltage divided by the ideal voltage, is used as one measure of "linearity", relationships can be derived which point out the design parameters affecting linearity. Calculations show that the deviation comes from the denominator. Thus, linearity equals $(\Delta_o - \Delta_1)/\Delta_o$ where $\Delta_o = \Delta$ at zero speed and $\Delta_1 = \Delta$ at desired speed.

Since most tachometers are designed to have nearly zero phase shift, the U term in the denominator must be zero or negligible. Then the linearity becomes

$Lin = \pm (W_o - W_1)/W_o.$

Referring to the equations and calculation form:

$$Lin = \pm (G_{1s}/G_{1s} + G_{1s})\,S'$$

$$\text{Lin} = \pm \frac{(X_{5u}/r_{2u})S^2}{[2r_{1u} + r_{2u}(X_{01}/X_{02})] - (X_{5u}/r_{2u})}$$

For most tachometers $X_2 = 0$

$$\text{Lin} = \pm \frac{(X_{5u}/r_{2u})S^2}{2r_{1u} + r_{2u}(1 + X_{5u}) - (X_{5u}/r_{2u})}$$

$$\text{Lin} = \pm \frac{(X_1/r_2)S^2}{2(r_1/X_{02}) + (r_2/X_{02})[1 + (X_1/X_{02})] - (X_1/r_2)}$$

Thus it can be seen that the linearity (or actually the departure from linearity) is proportional to X_1 and to S' and improves rapidly as r_2 increases. • • •

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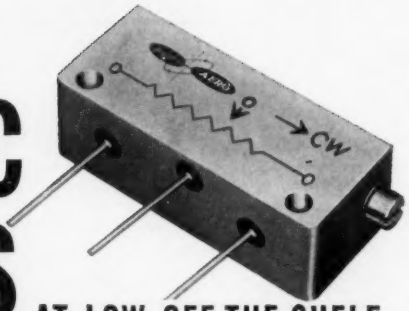

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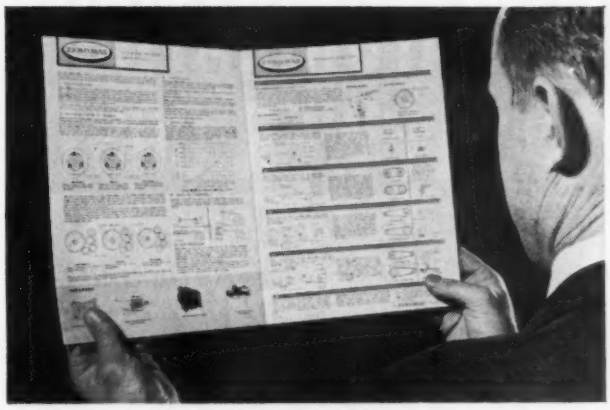

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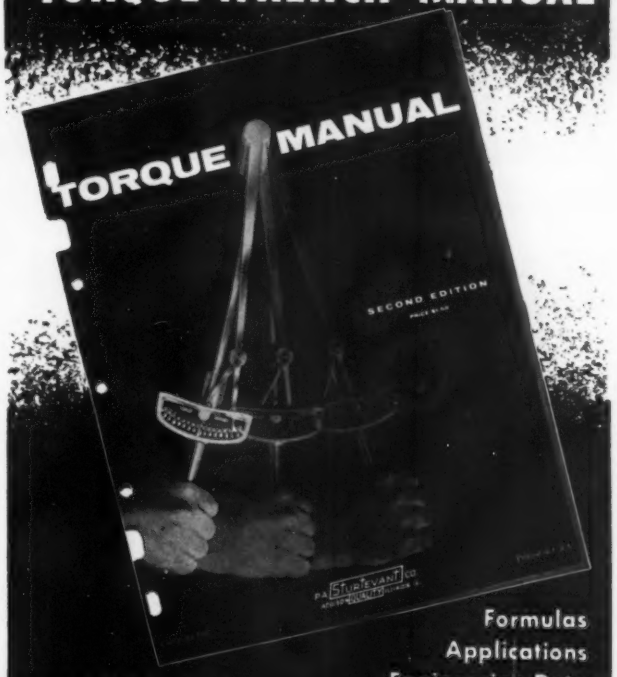

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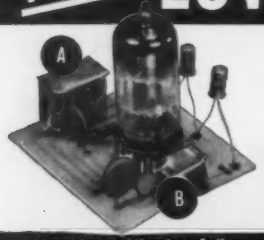

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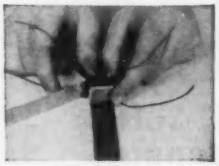
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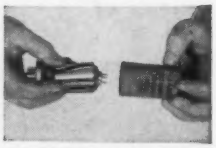
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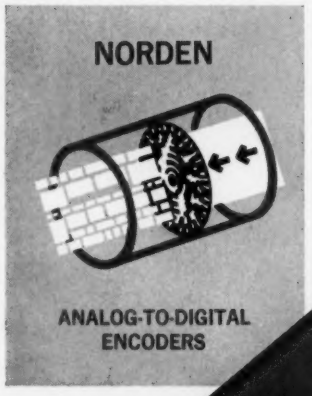

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- **Extremely high resolution in a single turn**—360,000 counts per turn in decimal format or 524,288, 1,048,576 and 2,097,152 counts per turn in binary format (2^{19}, 2^{20}, 2^{21}).
- **Exceptional accuracy**—at least as good as one quantum throughout 360 degrees of rotation as a result of unique time *and* position averaging inherent in the system.
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MICROGON transducers are supplied in solid shaft or hollow shaft configurations for convenient mounting on theodolites, tracking instruments, radar and communication antennas, rate gyro test tables, inertial platform gimbals, and automated machine tool rotary tables and lead screws.

CHARACTERISTICS OF MICROGON MODEL 512/219

Total Counts per Turn	524,288
Accuracy at Any Point	2.48 seconds of arc
Readout	19 bit parallel pure binary
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Transducer Torque	1.35 oz.-in.
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Electronics Weight	75 lbs.
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For illustrated brochure and complete specifications on MICROGON systems—or any other Norden encoders—write or call Norwalk, Connecticut, TEmple 8-4471 or TWX NWLK Conn. 21.

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CIRCLE NO. 35 ON INQUIRY CARD

Painting in background: "The Piping Shepherd," by Sir Joshua Reynolds, P. R. A. (1723–1792)

New cost savings for users of dielectric materials

. . . a progress report on the MYCALEX METHOD
from Jerome Taishoff, President, Mycalex Corporation of America

"I don't have to tell you about the profit squeeze. It's a hard fact-of-life throughout our industry today. That's why we feel the *MYCALEX METHOD*—the unique molding and finishing technique we recently developed—offers so much promise.

Sample quotations point to cost savings up to 84%

"The many months spent in the developing of this new process enable us to turn out better-performing products for less: savings we, in line with our policy, will pass along directly to our customers. And those savings promise to be substantial! Note the typical parts shown in the photograph below, as well as the two mechanical diagrams. As you can see, this new production technique reveals cost reductions of 78% and 84%, respectively, when compared to previous cost quotations." Just as important, the savings are in *addition to* the high reliability SUPRAMICA® ceramoplastics and MYCALEX® glass-bonded micas are noted for.

Savings plus quality with the MYCALEX METHOD

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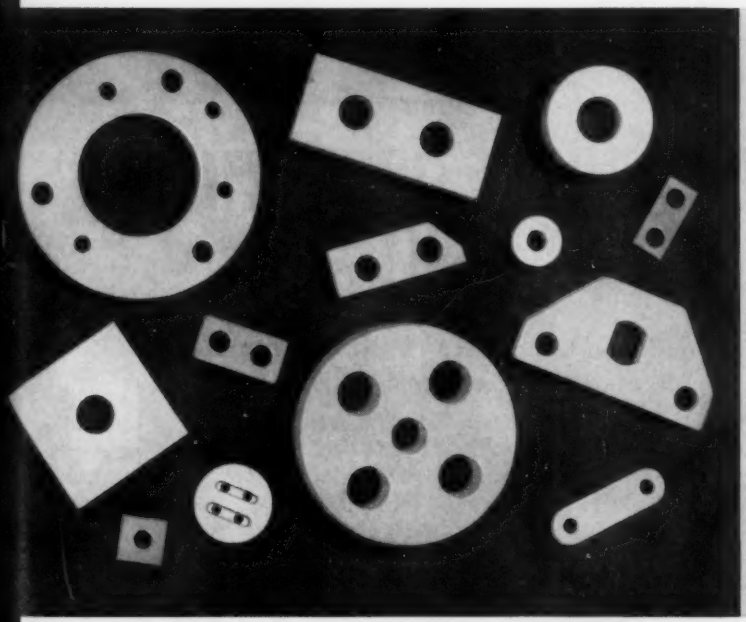
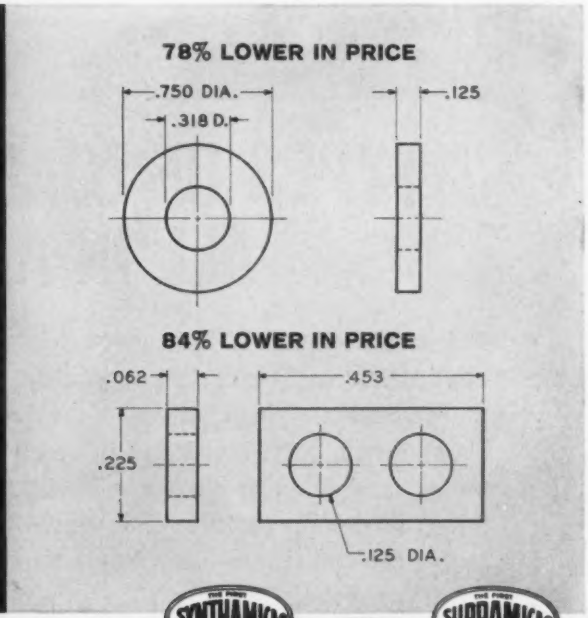
SUPRAMICA 620 "BB", 560 and 555 ceramoplastics and MYCALEX 410 glass-bonded mica. *Maximum Temperature Endurance* (unstressed): 1200, 930, 650 and 650°F; *Loss Factor* (10^6 cycles/sec.): 0.020, 0.010, 0.013, 0.010; *Compressive Strength* (psi): 30,000, 25,000, 40,000 and 40,000, respectively.

So for electronic insulation materials with the high-performance properties you must have—at a profit-protecting price — look into the new *MYCALEX METHOD*. Send your blueprints and drawings for specific quotations and information.





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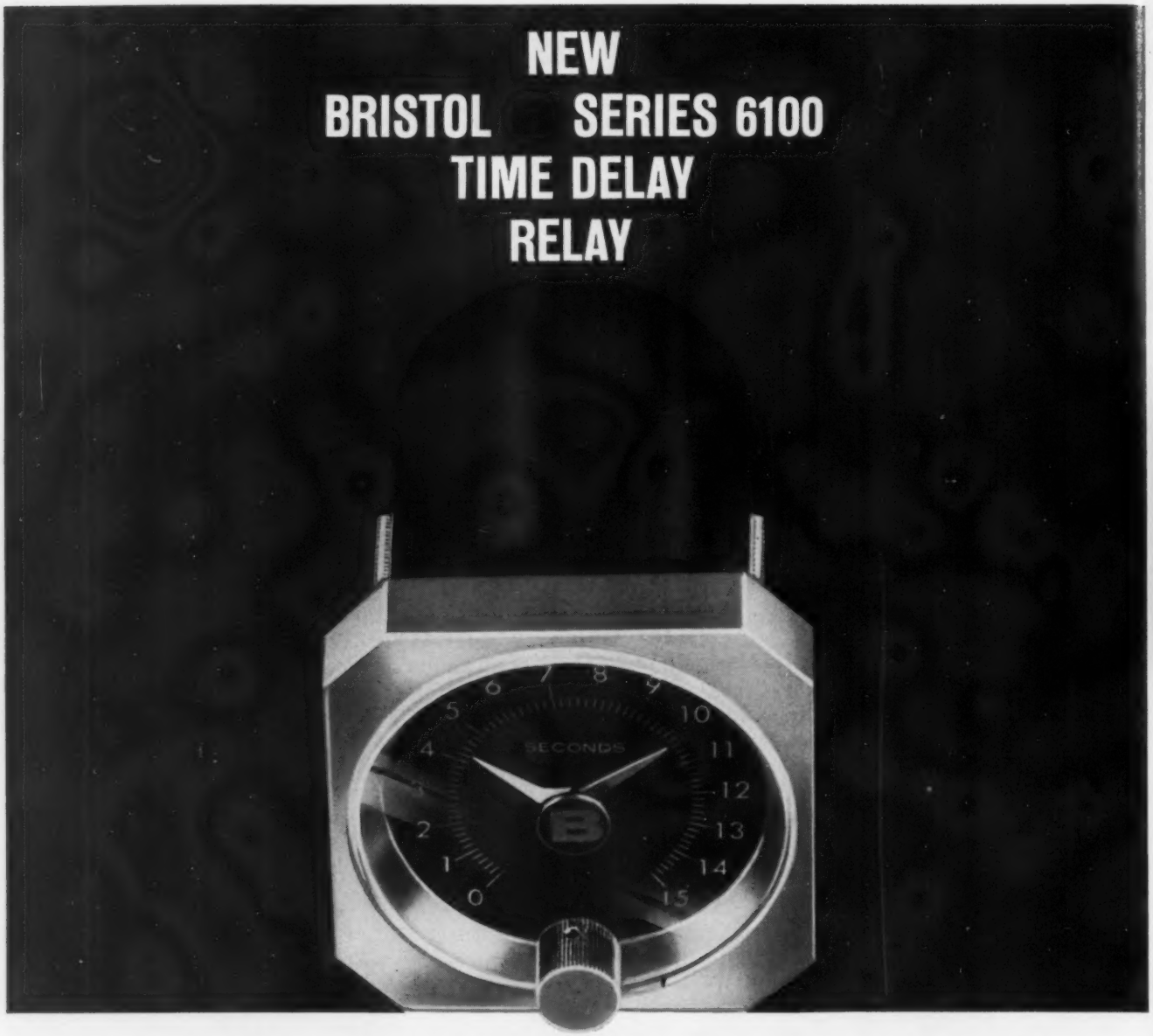

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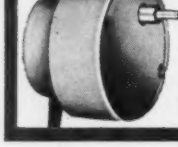

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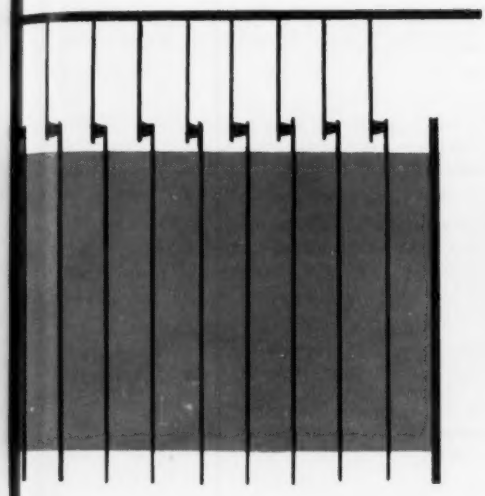
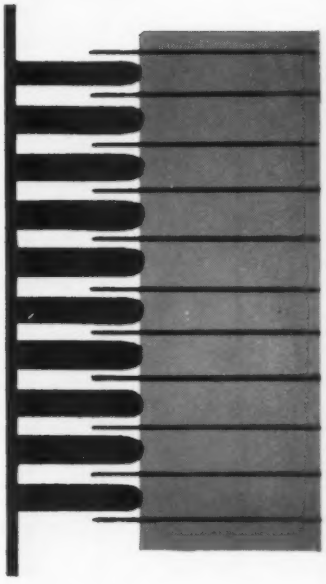
COMPONENTS DIGEST 24





SLIP RINGS Part I

Slip rings are rotary electrical couplings that conduct electrical signals or power between rotatably engaged members by means of sliding contacts. Until a few years ago, slip rings were used primarily in the electric power industry for motors and alternators. Manufacturing techniques at that time were coarse and accuracy was extremely limited. Materials used were usually copper and some form of low-cost insulation.

Today, slip ring applications range from miniature units for conducting signals in precision instruments, such as gyros and potentiometers, to complex assemblies for coupling power and signal circuits in rotary radar antenna systems. Slip ring manufacturers now must use techniques and materials that meet the standards of accuracy and reliability of the precision equipment in which they are being used.

Slip ring assemblies are being required to handle many types of circuits ranging from microvolts to over 30 kilowatts, currents from microamps to as high as 3000 amps and frequencies from dc to 100 megacycles. In some cases, hundred of circuits of various types are required in a single assembly. Other important considerations in slip-ring design are mechanical characteristics, such as configuration, structural strength, surface speed, torque and wear, and environmental characteristics, such as ability to operate reliably under shock, vibration, temperature extremes, humidity and high vacuum.

The great variety of demands that the slip-ring user can make in specifying an assembly and the complex problems and resulting cost that ill considered demands can cause impose an obligation on the user to develop better understanding of the problems and limitations in slip-ring design.

The purpose of this Digest is to provide the user some of this understanding by describing the various parameters and configurations of slip ring assemblies and discussing the problems and limitations that must be taken into account in specifying a design.

Previous Components Digests have been entirely staff written based on information received in answer to industry-wide questionnaires. In the case of this topic, however, information received from some manufacturers was so complete and so concisely directed to the purposes of the Digest, we are publishing sections of the material as received. The extent of valuable information provided warrants coverage of this topic in more than one issue. Part 1, in this issue, covering general aspects of the subject includes a comprehensive article on "Design and Use of Rotary Electric Couplings" by James F. Gordon of Pacific Scientific Co. and a section on slip-ring reliability based on information supplied by K. R. North of Electro-Tec Corp. Tables I and II are quick reference charts, prepared by G. Merker of Electro-Tec, that give a rough outline of the characteristics of slip rings for various applications.

The material provided by Electro-Tec engineers originated in an Electro-Tec Seminar covering many areas in the state of slip-ring art.

Future sections of this Digest topic will include more detailed aspects of slip ring design problems taken from these Seminar Papers and from extensive information supplied by the D. E. Makepeace Div. of Engelhard Industries Inc. Much of the Seminar information on such topics as friction and wear of sliding contacts, insulation materials, and electroplating will be useful in many other areas of engineering. The concluding section of the Digest series will cover special techniques and representative equipment of the various manufacturers who have sent us information.

COMPONENTS DIGEST

TABLE I • Slip Ring Application Chart

APPLICATION	SPEED (RPM)	TYPE ASSEMBLY	SIZE	MAJOR ELECTRICAL REQUIREMENTS
Strain gauge or thermocouple	100-25,000	Cylinder, Complete Assembly	10-50 rings	Low voltage, low current. Noise 50 microvolts to 10 millivolts maximum
Power Transmission	1-300	Disc or cylinder, silver-graphite or copper-graphite brushes	2-20 rings	Low voltage, high current. Current has been as high as 3,000 amperes. Voltage usually 220, 440 or 600 V.
Power for instruments used in aircraft or similar devices	1-100	Cylinder, silver-graphite or wire brushes	2-10 rings	Currents will usually not exceed 5 amperes. Voltage is usually 115 V (400 cycles power supply).
Signals for instruments used in aircraft or similar devices	1-100	Cylinder, wire brushes	4-60 rings	Low voltage, low current — usually milliamperes (100 is a maximum). Low noise 50 microvolts to 10 millivolts. Shielding may be required.
Radar pedestal a) Power Section	1-10	Cylinder or disc, silver-graphite brushes	4-10 rings	Same requirements as power transmission.
b) Signal Section	1-10	Cylinder, silver-graphite or wire brushes	50-300 rings	Low voltage, low currents, anywhere from 1 milliamp to 1 ampere at voltages up to 3000 V. Requires shielding in some cases.
c) Co-axial Section	1-10	Cylinder, silver-graphite or wire brushes	2-20 rings	Used as rotary joint. Faraday shield, co-axial terminals and leads. Used in 30-120 megacycle range. Shielding required all over. Attenuation 40-60 db can be achieved. Complex design involves individual treatment for each case.

Courtesy of Electro-Tec Corp.

DESIGN AND USE OF ROTARY ELECTRIC COUPLINGS

By James F. Gordon
Engineering Manager — Pacific Scientific Co.

Rotary electric couplings are of two general types, those that transfer energy or information between two members rotatably engaged by means of electromagnetically coupled or electrostatically coupled fields, and those that accomplish the transfer by means of slideably engaged conducting members. In a few instances, where the angle of relative rotation has been of the order of 360°, it is possible to use flexible "wind-up" cables. By far the greatest number of applications are for the direct, slideably engaged types. There are numerous approaches, many designs, and no small number of patents covering the art of such moving contact mechanisms. This discussion is limited to the slideably engaged type consisting of circular slip rings and mating brushes. The general use of such devices is at least as old as the earliest rotating electrical machinery. Our expanding technology, however, has more recently generated new and important requirements for such devices. Typical of the applications are multi-circuit couplings used to interconnect the gimbals on a gyro.

A typical coupling for such applications may consist of a group of slip rings having a diameter no greater than a tenth of an inch. The accompanying brushes usually consist of very fine precious metal alloy wire.

On the other hand, the requirement for large rotating missile guidance and space tracking antennae, plus a considerable variety of large centrifuge research and testing installations, has generated a requirement for massive rotary electric couplings. Some assemblies weigh thousands of pounds and are as large as a small car.

The big difference between the present applications and those of a few years ago is that precision performance is required, regardless of whether the rotary electric coupling unit is designed to operate reliably

in a miniature inertial platform assembly or is a massive device to carry power and instrumentation for a forty foot centrifuge.

The wide range of application thus covered requires a multiplicity of techniques and talents on the part of design and manufacturing. In the experience of the relatively few manufacturers of such devices, one user's design is rarely applicable to another's requirement. Every such manufac turer must maintain a staff of engineers constantly directed towards the solving of problems attending new requirements. Specialization is the rule rather than the exception. The cost of such items is usually high, due in a great part to the specialized requirements of rigid quality and process control, extensive use of precious metal, and the careful evaluation and testing of the finished assemblies to assure reliable performance. Nevertheless, there is no practical substitute for the direct contact brush and slip ring combination for the rotary electric coupling in most of the applications. Work is being done to advance the state of the art as rapidly as possible. Such activities are directed toward developing rotary electric couplings which do not degrade the system electrical or mechanical performance *when substituted for directly connected wires and cables.*

It is essential for the designer of a rotary electric coupling to be familiar with the actual system requirements in which the device must function. Reasons for this become more apparent with an understanding of the total requirements of such devices and the many variants that govern the form factors, choice of materials, and manufacturing techniques.

For most applications, the following requirements are listed in the order of importance to the user:

For Power Circuits

Cost
Electrical Contact Performance
Insulation Resistance
Life (Operating and Storage)
Dielectric Withstanding Voltage
Environmental Sensitivity
Envelope Size and Weight
Maintenance Considerations
Torque

For Signal Circuits

Cost
Electrical Contact Performance
Insulation Resistance
Cross Talk
Dielectric Withstanding Voltage
Bandwidth
Insertion Loss
Impedance Match
Torque
Life
Environmental Sensitivity
Envelope Size and Weight
Maintenance Considerations

These requirements are general. Their relative importance varies with the application, of course, and the best end result is achieved by proper attention to those requirements that establish the best *reliability* for the specific application.

TABLE II • Slip Ring Characteristics for Various Performance Factors

PERFORMANCE FACTORS	RING WIDTH	BRUSH TYPE	BARRIER WIDTH
Velocity V > 250 fpm V < 250 fpm	 .125 .020	 silver-graphite noble metal alloy wire	 .060 .030
Current above 2 amperes	.125-.500	silver-graphite brushes	Raised or Flush .060-.250
Current below 2 amperes	.020-.040	noble metal alloy wire .010-.020 diameter	Raised or Flush .030-.060
High Voltage 3000 V and above			Increase width and raise height 1/16 or 1/8 for longer creepage path
High Currents 100 amperes and above	Use rings in parallel to avoid very large rings and terminals		
High Speed*	As wide as possible to increase cooling surfaces.		
Low signal. Low noise. Low torque**	.020-.040	noble metal alloy wire .010-.012	.020-.040

NOTES:

* *Best designed as complete assembly. Cooling required by external means. Static and dynamic balancing very helpful.*

** *Usually very low rpm. Best designed as complete assembly with bearings and housing.*

Courtesy of Electro-Tec Corp.

Slip ring and brush combinations of rotary electric couplings are of two basic forms, regardless of size.

The first is the cylindrical ring as shown in Figure 1.

The second is the "platter" type shown in Figure 2.

The principal justification for the platter type is to reduce the over-all length of a multi-conductor assembly.

Power brushes for either platter or cylindrical rings typically are self-lubricating. Most of these use graphite in a mixture of the base metal. The percentage of metal is the higher and is usually copper or silver. Other materials and combinations are used. The use of silver is restricted to those assemblies from which the lowest possible contact resistance, both static and dynamic, is expected.

Signal type rings may be made of a number of materials. Fine silver, silver alloys, 24 K and lesser purities of gold, rhodium plates, gold plates, and platinum plates are examples of the materials in general service. Brush materials are typically fine wire alloys of platinum, gold, and less noble alloys and have the special requirements that they must exhibit the characteristic force of a spring in order to maintain the necessary contact pressure on the slip ring.

Manufacturers supply separate slip rings and brushes of all types as well as completely self-contained closed assemblies. Most manufacturers prefer to supply complete assemblies since this relieves the user of the responsibility of properly matching the brushes to the slip rings (often a very critical operation requiring a specialized skill). It also allows the manufacturer to have more control of the ultimate performance of his device. Such complete assemblies are not possible, however, in many cases. A common example of this is the slip ring brush combination in a synchro motor which utilizes the synchro shaft and bearings and synchro housing as mounting media.

COMPONENTS DIGEST

All in all, and this is not peculiar to the slip ring manufacturer, there is no such thing as sufficient use data from which the designer must create a reliable design. Actually, the rotary electric coupling designer should be in on the job from the outset and in close touch with other design personnel.

Insufficiency of information currently exists in present knowledge of metallurgy despite a considerable amount of past work. Some work is being done in the area of lubricants and compatible mechanical designs.

THE NATURE OF SLIP RING NOISE

The sliding contact electrical noise developed in rotary electric couplings is a result of the total variations in the flow of electrons between a ring and its corresponding brushes and vice versa. These variations are a function of the mating materials, finishes, relative sliding velocity, current magnitude and direction, temperature of the parts, brush pressure and degree of mechanical excellence, to name the more important ones.

The electrical variations that occur can be separated into those due primarily to instabilities in the mechanical structure, which can usually be reduced by careful attention to the structure, and those due to the variations in contact resistance depending upon type of materials, grain size, etc.

Noise due to mechanical variations is usually repetitive in nature; electrical noise between slip rings and brushes is very close to being statistical in nature. Noise performance is tested usually by passing a direct current through the circuit and observing the voltage developed between the brush and ring. See Figure 12.

THE CAUSES OF MECHANICALLY INITIATED NOISE

Slip Ring Eccentricity —

If a slip ring revolves off center, a change in relative velocity takes place, the wiper force varies, and, in addition, the contact point varies between point *a* and *b* as shown in Figure 3. Variations in resistance thus take place due to change of brush pressure as well as cyclic variations in brush surface conditions; the slip ring wears unevenly and may suffer reduced life. A variation in circuit resistance (the potentiometer effect) results when the point of contact moves back and forth along the brush arm. This latter is more pronounced with wire type brushes on small mechanisms than with block type brushes. These conditions become apparent as contact resistance variations when eccentricities of 0.001 of an inch or more are noted on a 0.375 inch diameter ring. The ratio of these dimensions holds for most diameters provided that they op-

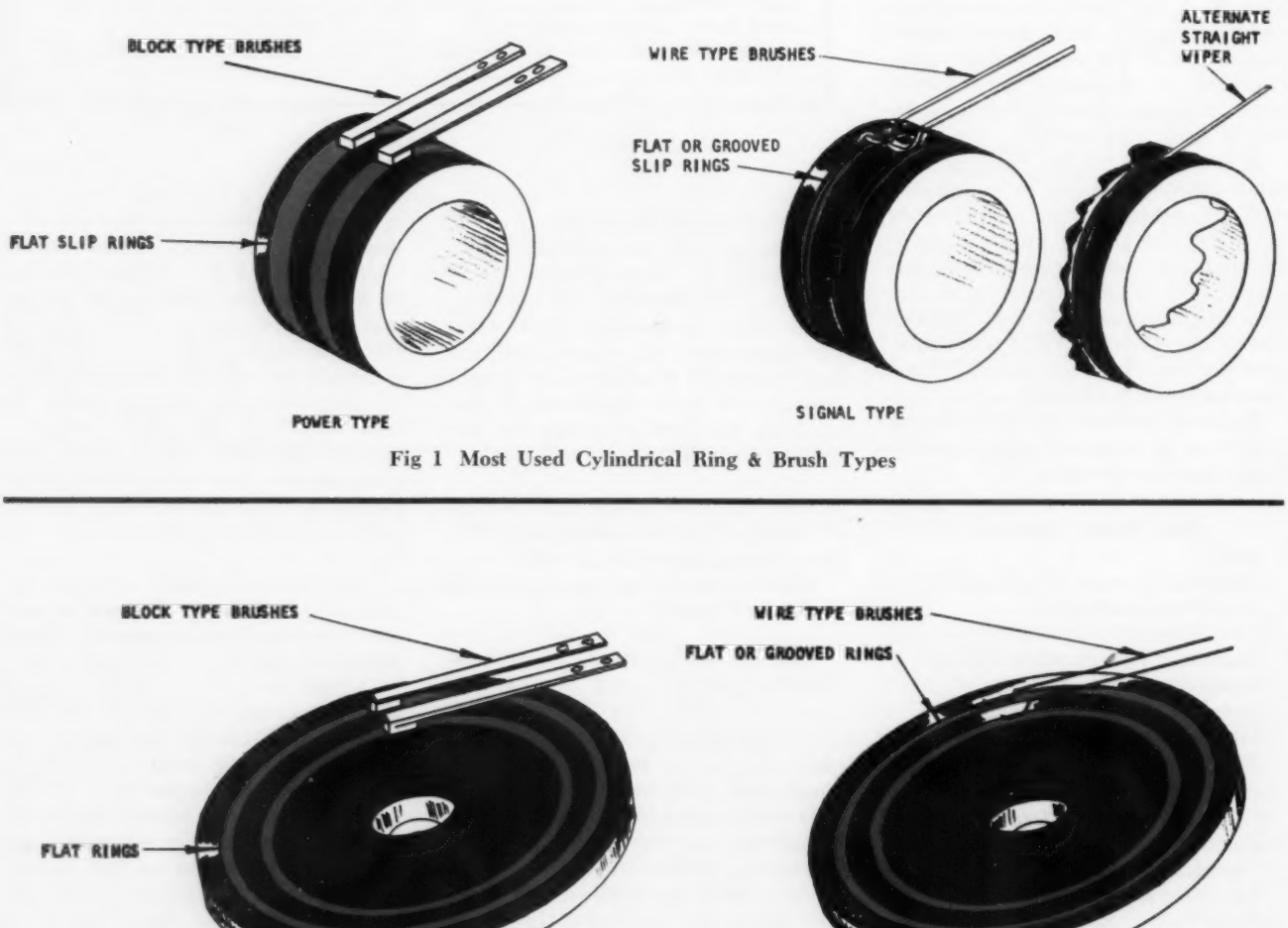


Fig 1 Most Used Cylindrical Ring & Brush Types

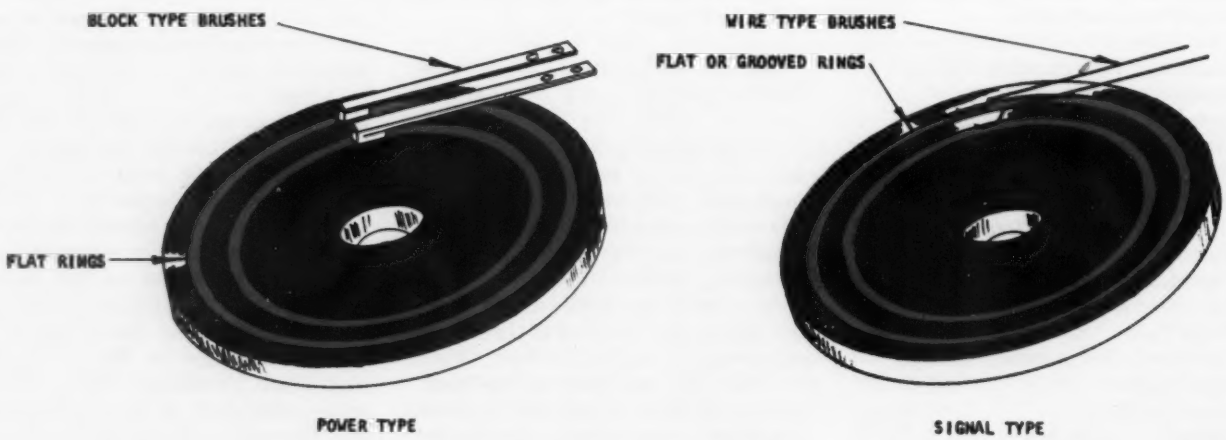


Fig 2 Platter Type Rings & Brushes

erate at relatively slow speeds. Degradation thus encountered becomes worse as speed increases.

When slip ring velocity is high, the problem of brush bounce increases. It is rare that an eccentric assembly, unless it's very bad, can actually impart sufficient velocity to the brush to make it leave the ring. Variation in pressure, however, creates a cyclic variation in resistance that is disturbing and undesired. Such action can excite resonances, especially in wire structures, which in turn can produce the potentiometer type of contact variation previously referred to and shown in Figure 4.

End Play —

Shaft end play can cause brushes to move to a different track and thus create variations in sliding contact resistance. In some circumstances, this can excite brush arms to vibrate at their resonant frequencies. This problem is less common than that due to slip ring eccentricity.

Shock & Vibration

Almost any mechanical deficiency working to produce electrical noise tends to appear worse under shock and vibration. The usual procedure is to assure that an absolute minimum of motion in any plane exists between the slip rings and the brush block mounts under the severest contemplated environment. Bearings play an important part here.

It is usual to design brush arm and cooperating structures to have resonance modes above the maximum shock and vibration limits of such excitation. Where this cannot be accomplished, it is often necessary to arrange more than one brush per ring in such a manner that they do not have a common excitation sensitivity axis. Occasionally a further design practice is to support one of a pair of brushes on a brush arm of different length to separate their resonance points. Multiple brushes at different angles usually solve most of the vibration sensitivity problems provided that the brush arm lengths are designed to the best practical minimum length and diameter.

Block type brushes of the motor/generator type used in clamp type brush holders are rarely used except for very high power couplings using currents of 100 amperes and up where the contact environment problems are somewhat different and are also less critical for electrical noise.

ELECTRICAL NOISE

The inability of a brush to make perfect contact with a slip ring, even when the mechanical design is excellent, and the workmanship is of the highest order, gives rise to a certain noise level, depending upon a number of modifying factors.

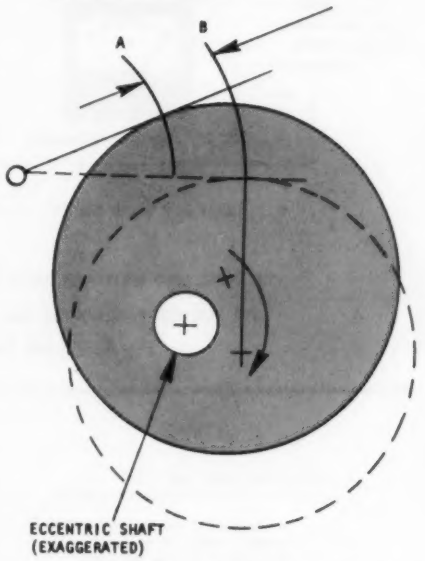

ARRANGEMENT SHOWS HOW POORLY CENTERED SLIP RING "WALKS" BETWEEN POINTS A & B ON A WIRE TYPE BRUSH. THIS WILL CREATE A CYCLIC VARIATION IN CIRCUIT RESISTANCE EQUIVALENT TO THAT OF A SLIDE WIRE POTENTIOMETER ELEMENT.
A
B
ECCENTRIC SHAFT (EXAGGERATED)

Fig 3 Slip Ring Eccentricity Impairs Performance

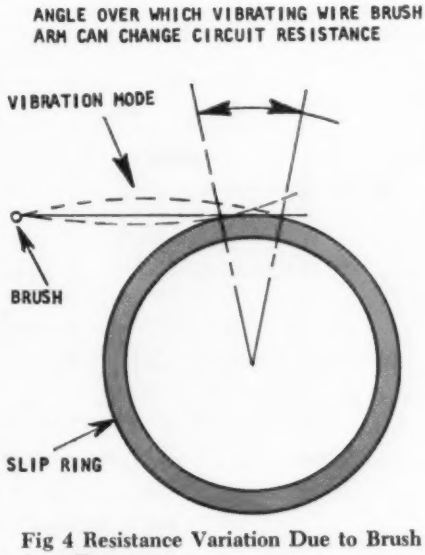


Fig 4 Resistance Variation Due to Brush Arm Resonance

Wherever two metal surfaces are slideably engaged, the character of one with respect to the other undergoes a constant physical change. Magnify, for example, a macroscopically smooth surface, under a microscope. You will discover that the surface is no longer smooth but, instead, is composed of a myriad of very small hills and valleys. When one of the hills on a slip ring is engaged with a hill on the brush, an electrical contact is made at that point. Since there are many hills, and many valleys, which are distributed over the engaged surfaces in a more or less random nature, the probability that all of the hills will be over all of the valleys is completely remote. As a result, electrical contact varies in accordance with this statistical contact point distribution. The number of hills in contact on both surfaces will vary. Additionally, each hill will not be of exactly the same height or area so that the pressure brought to bear during momentary contact is changeable, thus modifying the instantaneous ability to transfer electrons. During the process of such sliding surface engagement, particles are worn off or displaced from both surfaces. Some deformation of particles takes place due to force of friction. Sometimes heating alters the surface condition. Surface contaminations also occur due to chemical reduction due to the particular atmosphere to which the sliding surfaces are exposed. All of these variables cooperate to produce a general contact variation which is very nearly statistical. Current that passes between two such surfaces is subject to the algebraic sum of all of the individual contact conditions at any instant. The result, of course, is that the pattern of the electron flow between the two surfaces is completely descriptive of the contact condition. A direct assessment of contact condition thus may be made by observing the potential differences between the brush and slip ring on an oscilloscope during operation. (See Figure 12)

It is the practice to define slip ring/brush contact resistance as follows:

1. Static terminal resistance —
   The dc resistance between a specified brush terminal and its corresponding ring terminal with the device non-rotating.
2. Static contact resistance —
   The dc resistance between the brush surface and the slip ring at the point of contact with the device non-rotating. (A difficult job to test, it is usually accomplished by passing a dc current through the circuit and measuring the potential drop between the brush and ring with needle probes as close as possible to the brush/ring contact with the device non-rotating.)
3. Dynamic contact resistance —
   The statistical variation in contact resistance during rotation. (This is best determined by observing the peak voltage developed across the brush and ring during operation with a known constant dc current as observed on an oscilloscope and from this determining the *peak dynamic*

COMPONENTS DIGEST

resistance. When maximum performance is required, it is not always satisfactory to assess such noise on RMS reading voltmeter devices or bridges, because of the large errors possible, or the narrow bandwidths of some measuring equipment.)

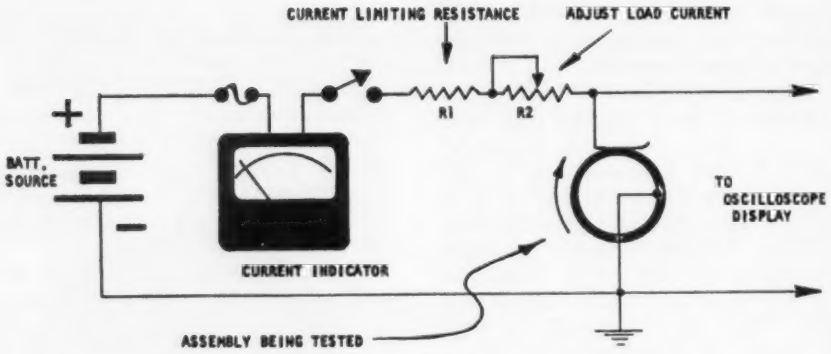
TESTING SLIP RING PERFORMANCE

Dynamic Contact Resistance (Noise)

Practically all contact resistance noise tests can be made with dc. It is often necessary to specify the current at which the tests are to be made as well as the slip ring RPM in order to make a relative assessment of performance. In addition, the point in time of life at which the noise measurement is made is quite important.

Since, in a well designed brush/ring combination, the static, as well as the dynamic resistance is of a very low value, the source impedance then, for qualitative and quantitative testing becomes ideally low and the following circuit configuration (Figure 5) is simple and satisfactory, even for the most delicate rotary electric couplings.

For extremely low current evaluation, some sort of high gain pre-amplifier ahead of the oscilloscope is necessary. A minimum bandwidth of 100 KC is adequate for most applications, 1 MC is a better choice and is to be recommended as a desirable figure for all oscilloscopic observations except for RF noise which will be discussed later. The low noise source impedance (with a properly designed REC unit) is well suited to obtaining the best noise figure with any pre-amplifier. The input noise level of the pre-amplifier used limits the level at which noise can be measured. Slip ring/brush combinations are now being made that have low enough noise levels to require excellent pre-amplifier noise figures. Commercial pre-amplifiers available for oscilloscopes will have peak noise figures, referenced to the input, of 25 micro-volts or better with an ohm or less at the input. Some transistor units are available or can be designed to work down to two or three micro-volts at narrow bandwidths. Care must be exercised, however, in that typically such circuits have a low dynamic range and thus high level transients of short duration may never be passed. A practical low-distortion wide-band vacuum-tube



THE TOTAL LOAD RESISTANCE (R1 + R2) SHOULD BE AT LEAST 1000 TIMES THE MEASURED PEAK DYNAMIC RES. TO OBTAIN .1% MEASUREMENT ACCURACY

Fig 5 Simple Noise Test Circuit

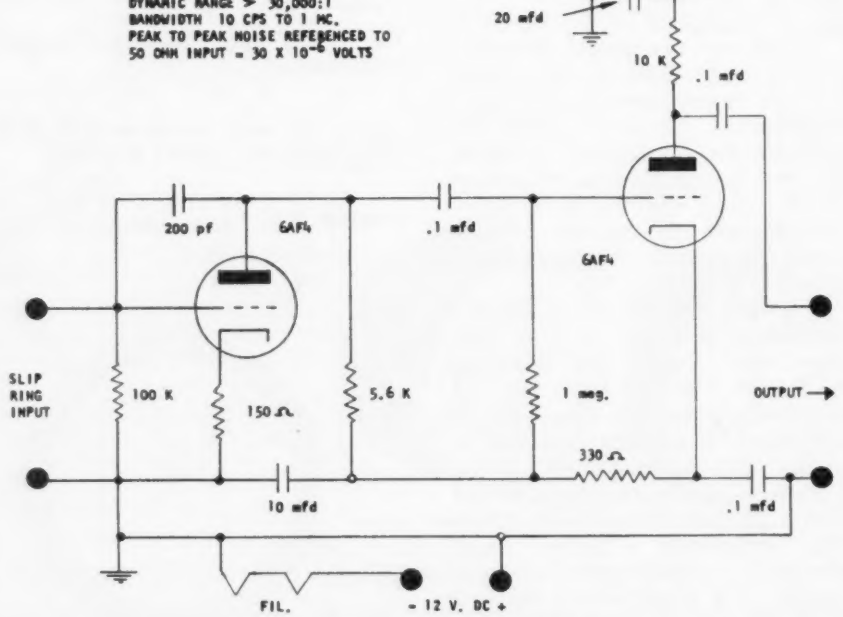


Fig 6 Practical Noise Pre-Amplifier

amplifier of low noise characteristics over a large dynamic input range satisfactory for such measurements is shown in Figure 6.

A regular laboratory test facility is shown in diagram in Figure 7. A photograph of such a facility is shown in Figure 8.

It is often desirable to superimpose an oscillatory motion upon the normal shaft rotation of REC units and a reversing mechanism is mandatory.

Because of the low levels involved in some tests, the measurement facility should be placed within a screen room to eliminate extraneous noise interference.

Where there are numerous conductors in a single rotary electric coupling, although laboratory and engineering design evaluation is concerned with each specific slip ring and brush combination, it is permissible in many instances to place all rings and brushes in series and thus read out the noise developed across the entire group. For a 100 ring assembly, for example, the noise will add algebraically. Thus, if each ring contributes a noise voltage of 0.001 volt at a specified common current, the square root of the sum of the squares would be 0.010 volts for the 100 rings. Although subject to some error, by using a large safety

factor, the method saves considerable time and, with experienced operators, becomes reasonably reliable.

Accurate noise testing of such devices depends a great deal on quality measuring equipment and experience at interpreting the results. At the present time, there are no accepted standards for such measurements except the dictates of good engineering practice. The users of such devices must thus rely heavily upon the experience, engineering stature, and proven performance of the manufacturer.

DIELECTRIC WITHSTANDING VOLTAGE

Dielectric withstanding voltage is not usually a problem in large units (2" diameter and up) but becomes a problem where the physical size is small. Breakdowns can occur both internally and on the surface. The practice is to apply a dc or ac potential for a specific period between the various conductors and the frame or other normally insulated parts of the circuit. Good design practice is to establish breakdown values of at least four times the maximum peak service requirement.

LEAKAGE RESISTANCE

Two types of leakage problems occur in slip ring assemblies. One is the surface leakage between adjacent rings. The other is the leakage through the body of the insulating material. Both are tested for in the normal manner, usually with an applied potential. Good design practice dictates around 1000 megohms at +500 v dc test potential. This value is reduced for very large units because of the increased leakage areas.

Surface leakage can be a problem in service if means are not taken to prevent collection of wear debris between adjacent slip rings. The same considerations apply to the brushes but are usually less critical. Impregnation or a surface sealer should be applied to large cast or fabricated insulating materials operating in high humidity.

CROSS TALK

Cross talk occurs as a result of stray electrostatic and/or electromagnetic coupling between adjacent slip ring and brush conductors. In the past, requirements have not been stringent in these respects. Increased requirement however for more instrumentation in smaller spaces is focusing considerable attention on this functional problem and has generated some new design requirements. Testing of cross talk is

TYPICAL TEST SET UP FOR LIFE AND DYNAMIC CONTACT RESISTANCE

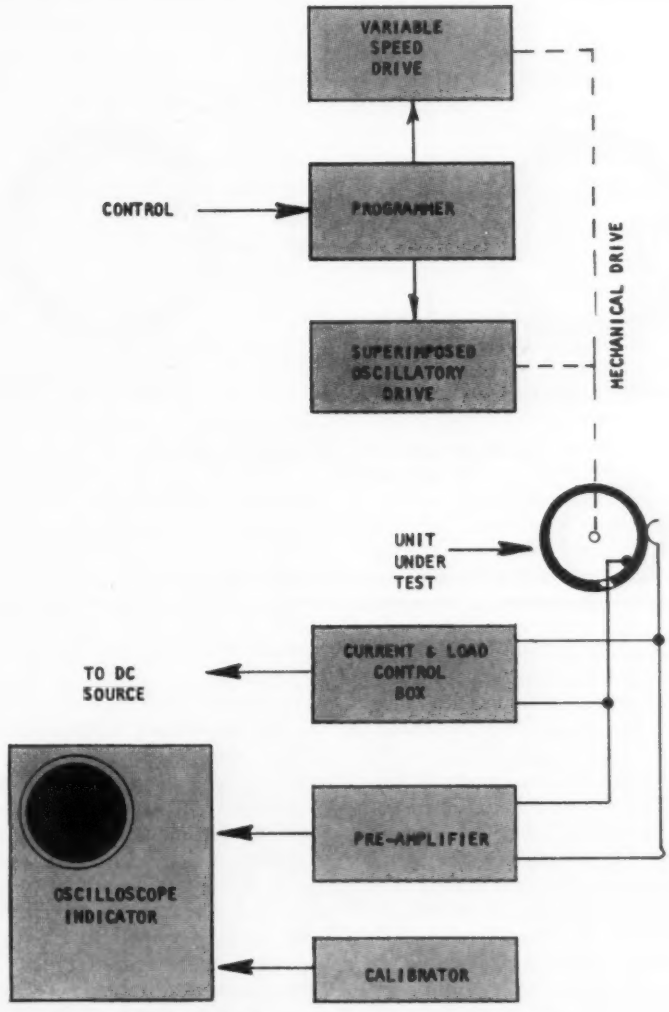


Fig 7 Block Diagram of Typical Test Facility

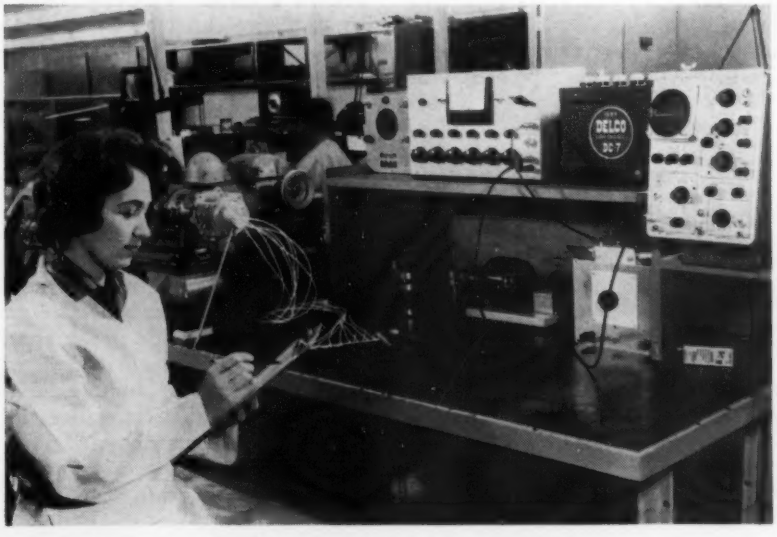


Fig 8 Photograph of Noise Test Facility

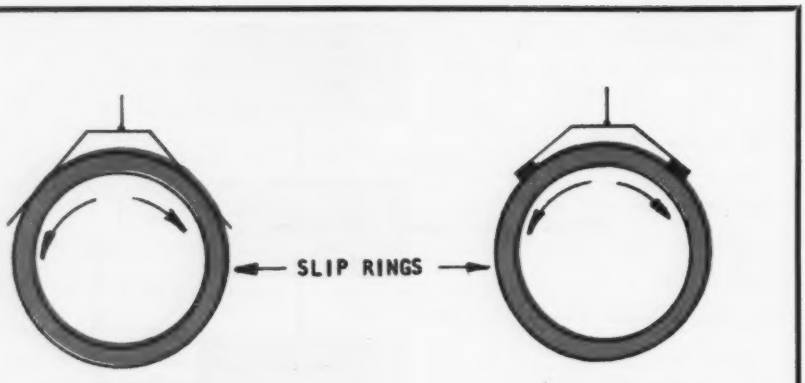


Fig 9 Typical Arrangement of Brush Pairs

similar to the testing of cross talk in any adjacent wire transmission system and is usually established on the basis of the specific system requirements.

Typical capacitances between slip rings in normal structures of all sizes vary from between 15 and 150 pf and about a third of that value for the brush assemblies. Capacitance of the circuits to the frame vary widely with the design. It is usual to specify capacitance to be tested at 1 megacycle.

Cross talk problems, as would be expected, increase with frequency. They are sometimes aggravated with increased speed of rotation.

LIFE

Life span of a rotary electric coupling depends heavily on the type of service and the environment. Where it is possible to utilize graphite brush lubricants, the life may be considerably extended. Certain very small units will not physically accept the use of dry lubricants and are almost entirely designed to use fine precious metal brushes. Minimum slip ring width at the present state of the art is about 0.015 inches with a ring to ring center spacing of about 0.025 inches leaving a 0.010" space between rings.

The extended life requirement obviously presents a real problem. It is not normal to expect such devices to operate with relative slip ring/brush velocities of more than 100 feet per minute reliably in the dry metal-to-metal state. It is possible, with special lubricants, to operate up to 400 feet per minute. There is a wide variation in life depending upon choice of materials dictated by individual requirements. As a general rule, a lubricated miniature unit using wire brushes will give up to four times the life performance of a non-lubricated unit of the same type. Where it is possible to run the assembly in an oil bath, the life may be upped to ten times that of some unlubricated types. The oil bath presents problems of sealing, is restricted to finite velocities, narrow ambient temperature range, takes more space and weight, thus is not regularly used. Properly lubricated units often exhibit as low a dynamic noise resistance as unlubricated units. Such performance is inherent in the design and should not be relied upon across the board.

DESIGNING AROUND THE NOISE PROBLEM

The few U. S. manufacturers of quality rotary electric couplings are in the business because of some unique abilities and/or processes which have been developed to provide performance in this field. In no small number of instances, especially with miniature units, a practical performance and reliability has been obtained only by the strategic use of precious metals, alloys, and newly, and sometimes, specially developed plastic insulation materials. Along with these practices, manufacturers have developed a number of highly specialized techniques which are proprietary and not available for publication.

Certain things are, however, well known to the industry. For example, gold in its pure state is an excellent metal surface protection. It is also a relatively good electrical conductor. It thus provides a good sliding electrical surface. For that reason, most of the miniature slip rings in critical applications use gold or gold surface rings of some sort.

Miniature brushes are usually made of precious metal alloys. Best known among there are Paliney #7, Ney-Oro-G, and Ney-Oro-28-A, initially manufactured by the J. M. Ney Co. Those combinations which provide the longest wear life characteristically produce the highest dynamic contact resistance. Those combinations showing lowest initial dynamic contact resistance usually show a shorter life. Obviously, a more intimate metal to metal contact argues more friction. A good combination, where the environment is compatible, is to use a lubricant, provided that the lubricant does not degrade the dynamic contact resistance. Life is considerably extended by such lubrication, as previously mentioned.

On miniature assemblies, particle contamination can be a real hazard. The design must be such that a minimum of wear particles is generated during life, that no external particles can enter, and that foreign grease, oil or bearing debris are excluded from the contact area.

Increasing contact area will usually reduce dynamic contact resistance. This cannot be practically accomplished by increasing the contact area of an individual brush because of the difficulty of keeping the total increased area in uniform contact. However, by adding additional individual small-area brushes, a greater effective contact area may be realized. With two brushes per ring, the dynamic contact resistance will be rendered to 0.707 times the value of a single brush. Good design practice dictates the use of at least two brushes per ring regardless of size. With four brushes per ring, the dynamic contact resistance will be 0.707 times the value established for two and so on. Use of six brushes per ring provides some improvement over the use of four. Except in extreme cases, use of four is an excellent compromise. The use of brush pairs mounted as shown in Figure 9 is accepted practice for units that must operate bi-directionally.

Wire type brushes are designed to operate either on a flat surface (Figure 10-a), in a U groove (Figure 10-b), or a V groove (Figure 10-c).

Type *a* is often the easiest to make but does not capture the wiper and thus is subject to vibration noise. Type *b* captures the wiper to some extent but is subject to the collection of wear debris more readily than *a* or *c*. Type *c* has the advantage of two contact points per wiper (helps reduce noise), and is captured against vibration along one axis. The wear track is also maintained in a constant manner throughout life.

Block type brushes (Figure 9-b) mounted on brush arms are usually of the self-lubricating metal graphite type and operate on flat ring surfaces. In some instances, ring grooves are used to capture such brushes. This is the exception rather than the rule.

The wire brush finish as well as the ring finish is important. The best state of the art produces about a 3 microinch finish on miniature slip rings of silver or gold. Normal practice is to run-in a newly assembled unit for a specific period. It is then examined visually and electrically for any damaged rings. A good brush and ring combination will result in a burnished surface on the ring as a result of such "run-in." Any tendency of a miniature slip ring to exhibit galling portends very short life and poor dynamic contact resistance and is to be avoided in design. A single blemish on such a ring may develop a rough surface all of the way around in a relatively short time.

Where block-type metal-graphite brushes operate on large fine silver, coin silver, or copper rings, wear lines normally appear immediately upon the rings. Such brushes require a relatively long run-in period after being pre-contoured to the approximate slip ring circumference. It is not usual to place better than about a 16 microinch finish on such units. Care must be taken, however, not to leave tool marks which behave like minute threads which tend to bias the brushes to one side during rotation causing more than normal wear and increasing the dynamic contact resistance.

Most slip ring brush combinations, regardless of size or shape, have three operating ranges:

- The operating range below which the voltage is insufficient to break through the normal surface films. (On some material combinations this is very low, on others high.)
- The operating range of current over which the dynamic contact resistance is relatively constant.
- The overload range over which the dynamic contact resistance increases with current. Burn-out of silver graphite or melting of wire type brushes usually will take place very rapidly at this point.

Figure 11 is a typical curve showing the variation of dynamic resistance with current. This condition is modified by the relative velocity. It is not unusual for the maximum current at which the dynamic resistance remains constant to be lower as the velocity increases. *The reliable operating range of current is well within the constant level range.* Above that value, life is impaired by contact heating. Below the range, the increased dynamic resistance could, in some critical applications, impair performance. This latter value is usually very low, however, for a modern quality unit (see Figure 11).

The user of a rotary electric coupling should be aware of the limitations of such a device before using one in his system. It usually increases the system reliability if the REC designer can be brought in to the initial stages of the planning.

As a matter of convenience, certain structures can be used interchangeably for power or signals. A silver-graphite block type brush operating on a fine silver slip ring will exhibit excellent low noise signal performance and will have an excellent range of current over which the dynamic resistance remains constant. However, due to filming during extended operation of the interfaces, the level of

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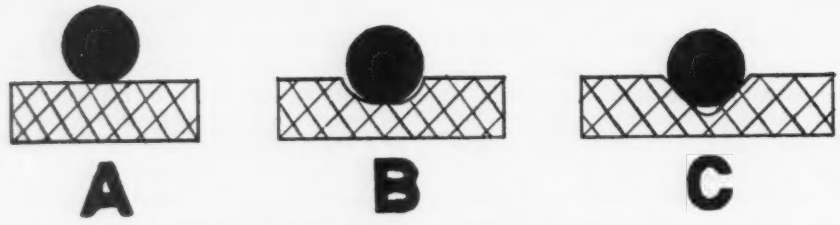

CROSS SECTION OF MOST GENERALLY USED WIRE BRUSH AND SLIP RING TYPES (SEE TEXT)

Fig 10 Typical Wire Brush and Ring Arrangements

current below which the dynamic contact resistance starts to increase if the ring is not kept clean is somewhat higher than for miniature assemblies using 24 K gold rings and gold alloy wipers. Total operational life expectancy, however, is many times better for the silver graphite on silver.

RADIO FREQUENCY NOISE

A slip ring brush combination, as previously stated, produces a current variation that comes close to being statistical. This fact means that a reasonably uniform noise spectrum is produced. Measured HF noise varies considerably between structures. The total noise power produced increases with current but the spectrum distribution may vary.

The actual form of the assembly, i.e., length of wiper arms, interface capacitance between brushes and slip rings, etc., can cause tuned circuits which can be excited by such noise. The noise spectrum, depending upon the specific arrangement may be either reinforced at particular frequencies or conversely exhibit frequency bands of little or no energy. Radio frequency noise is both radiated and conducted from the ring brush interface. The radiated variety can usually be shielded at the assembly and is accomplished readily since most assemblies are built within metal enclosures. The conducted noise is the biggest problem since all of the interconnections to such a device are potential noise transmission lines. To this extent, *the eventual HF noise performance of such couplings can only be evaluated after initial assembly into the end use system.* Criteria may then be established on the basis of laboratory tests for acceptable units in that particular system. When these factors are taken into account the HF noise problems are greatly reduced.

When slip rings and brushes operate in the range above the constant resistance levels shown in Figure 11, there is evidence of increased electrical erosion. The effect of such erosion can readily be detected by running identical assemblies with and without current. The current level below which no such erosion takes place is referred to as the "dry circuit" condition.

Brush pressure is a great factor in the dynamic contact resistance. A compromise must be made since

- High brush force to obtain high pressures per unit area, while initially reducing noise, eventually raises it as wear progresses.
- High brush force increases torque.
- Low brush force increases sensitivity to shock and vibration.
- Low brush force increases contact resistance but extends life.

The compromise again depends upon material choices and operating environment. For this reason, there can be few straightforward and generally applicable ground rules covering all design applications.

The Insulation Problem —

Slip ring assemblies are designed and manufactured by three basically different methods.

The rings and insulating parts are separately machined, following which they are stacked or "sandwiched" and are held together by through bolts or other clamping means. Leads are soldered, welded, or bolted to the inside of the rings.

The rings are separately machined and held in a fixture, then encapsulated or cast in an insulating plastic, following which they are machined to size. Leads are soldered, welded, or bolted to rings.

Pre-cured and pre-grooved insulating body (usually plastic) has slip rings electro-deposited in the grooves. Following this, the assembly is machined to size. Leads are attached to rings by molecular bond.

The first method creates many leakage paths between rings and is subject to degradation of insulation resistance due to moisture absorption.

The second method, if the casting is done under pressure, becomes reasonably homogeneous. In the curing process, however, the plastic insulation is likely to shrink away from the metal parts creating cracks and voids. The extent of such degradation depends upon the character of the materials. Any cracks whatever between the conductors are potential sources of insulation breakdown.

The third method, somewhat more sophisticated than the first two, casts the insulating material and removes the stresses by curing, and after shrinkage, before machining. This insures a crack-free form as an insulator upon which to build the rings by electrodeposition.

Surface leakage across the insulating barriers increases if the insulating material surface absorbs moisture. Some materials are better in this respect than others. Use of raised barriers between rings materially lengthens the surface leakage path and it is good design practice to provide them whenever possible. Where space between rings allows it, a groove may be cut in the insulating material in lieu of the raised barrier.

Insulation of the brush mounts closely follows the same kind of insulation design procedure involved in the making of a terminal board. The materials used should be every bit as good as those used for the slip ring assembly.

DESIGNING FOR REDUCED CROSS TALK

Factors influencing cross talk due to electrostatic coupling are the mechanical proximity of the conductors to each other and the dielectric constant of the insulating material. While it is possible to electrostatically shield both the slip ring and brush leads, it becomes costly and wasteful of space to place electrostatic shields between slip rings themselves. Since, for the best results, any shield between rings should carry through electrically to the mating brush shields, this requires additional slip rings and brushes. Figure 13 shows several methods for providing electrostatic shields through rotary electric couplings.

Not much can be done about magnetic field coupling in rotary electric couplings. The best thing to do is to attempt to physically separate the sensitive circuits from the interfering sources. This is a good idea on any assembly and is also very effective in reducing electrostatic coupling.

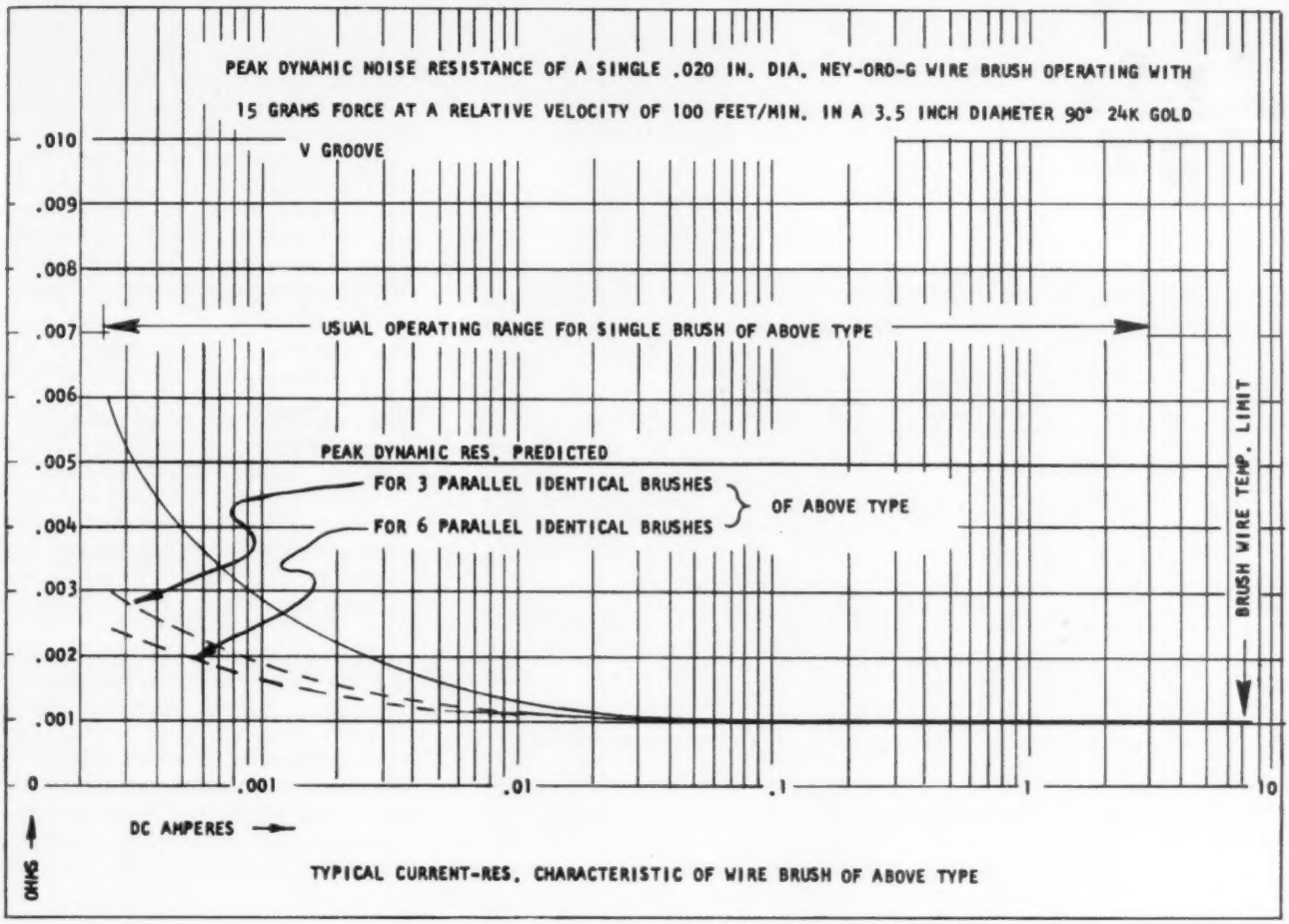

Fig 11 Variation of Dynamic Contact Resistance with Current

A third source of cross talk is coupling through a common ground loop. The best way to get around this, where interference can develop is to use separate through grounds on all conductors. Figure 13 shows this approach.

One of the best ways to reduce cross talk between power and signal circuits is to use low impedance signal circuits. This method is usually inherent in the system design but any effort in this direction is well worthwhile.

Cross talk increases with frequency; that due to electrostatic coupling will double in amplitude with every octave increase in frequency.

SPECIAL APPLICATIONS OF ROTARY ELECTRIC COUPLINGS

High Speed

Rotary electric couplings operating at speeds of 10,000 RPM and upward present special problems. Highly precise machining and balancing is an absolute must. Silver graphite brushes appear to be best in most applications. Fine silver rings do well. Where contact resistance is not too important, harder ring materials such as platinum or rhodium may be used. Because of frictional heating, auxiliary cooling is often necessary. Air blasts are one method of removing

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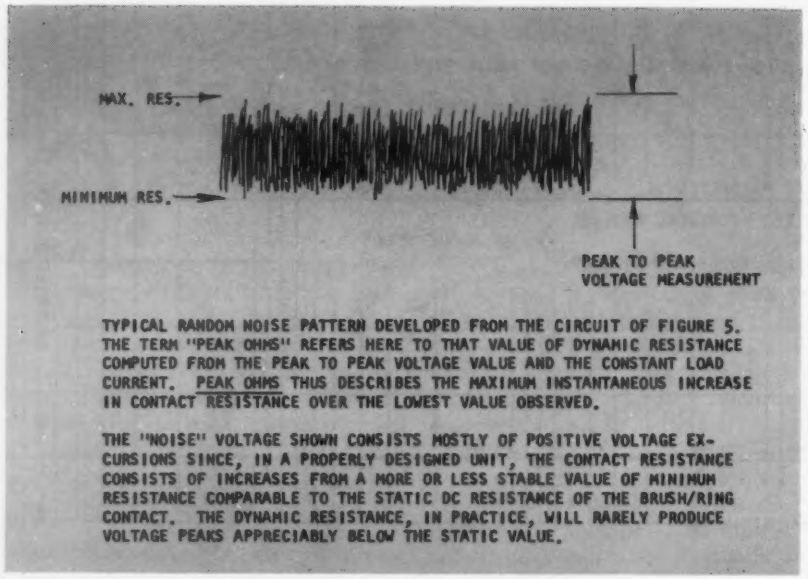
MAX. RES.
MINIMUM RES.
PEAK TO PEAK VOLTAGE MEASUREMENT
TYPICAL RANDOM NOISE PATTERN DEVELOPED FROM THE CIRCUIT OF FIGURE 5. THE TERM "PEAK OHMS" REFERS HERE TO THAT VALUE OF DYNAMIC RESISTANCE COMPUTED FROM THE PEAK TO PEAK VOLTAGE VALUE AND THE CONSTANT LOAD CURRENT. PEAK OHMS THUS DESCRIBES THE MAXIMUM INSTANTANEOUS INCREASE IN CONTACT RESISTANCE OVER THE LOWEST VALUE OBSERVED.
THE "NOISE" VOLTAGE SHOWN CONSISTS MOSTLY OF POSITIVE VOLTAGE EXCURSIONS SINCE, IN A PROPERLY DESIGNED UNIT, THE CONTACT RESISTANCE CONSISTS OF INCREASES FROM A MORE OR LESS STABLE VALUE OF MINIMUM RESISTANCE COMPARABLE TO THE STATIC DC RESISTANCE OF THE BRUSH/RING CONTACT. THE DYNAMIC RESISTANCE, IN PRACTICE, WILL RARELY PRODUCE VOLTAGE PEAKS APPRECIABLY BELOW THE STATIC VALUE.

Fig 12 Interpretation of Noise Pattern

heat. Attention to the thermal conducting characteristics in design can help to relieve hot spots. It is sometimes possible to lift the brushes from a slip ring assembly and to bring them into momentary contact long enough for a read out where such devices are used in instrumentation amenable to such procedures. The best rule is to keep the ring diameter as small as is practicable.

HIGH TEMPERATURE

Rotary electric couplings can and are being designed for high temperatures. Up to ambient temperatures of +185°C, presently available materials can be used for both rings and insulators, etc. The epoxies, however, are borderline at these temperatures. Silicone laminates have some application.

At the present state of the art, nothing is available in the way of compatible contact materials above +150°C that will give performance comparable to that which obtains at the lower ambient temperatures. Each and every application must be considered on its own merits. Platinum slip rings with silver graphite brushes

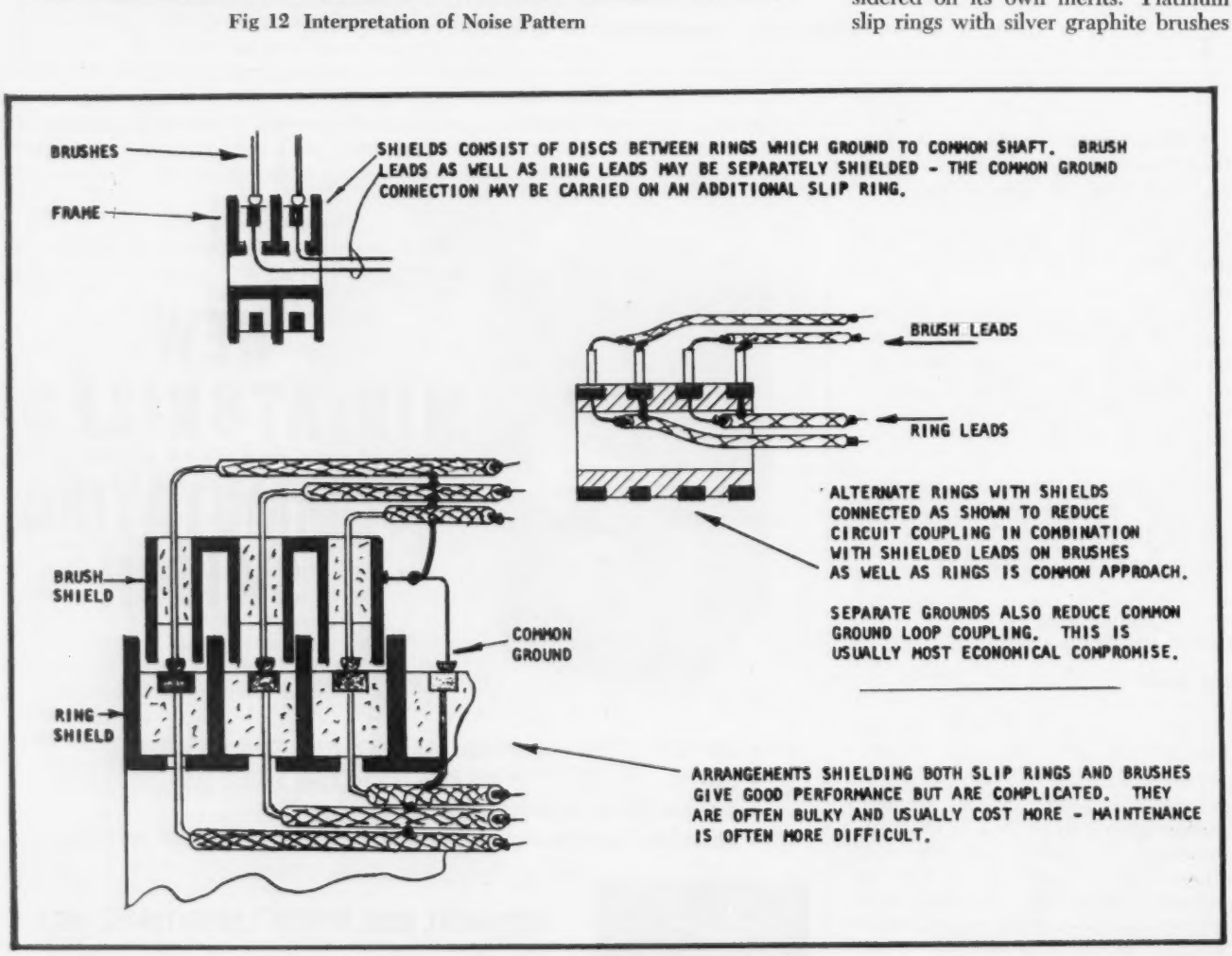
BRUSHES
FRAME
SHIELDS CONSIST OF DISCS BETWEEN RINGS WHICH GROUND TO COMMON SHAFT. BRUSH LEADS AS WELL AS RING LEADS MAY BE SEPARATELY SHIELDED - THE COMMON GROUND CONNECTION MAY BE CARRIED ON AN ADDITIONAL SLIP RING.
BRUSH LEADS
RING LEADS
ALTERNATE RINGS WITH SHIELDS CONNECTED AS SHOWN TO REDUCE CIRCUIT COUPLING IN COMBINATION WITH SHIELDED LEADS ON BRUSHES AS WELL AS RINGS IS COMMON APPROACH.
SEPARATE GROUNDS ALSO REDUCE COMMON GROUND LOOP COUPLING. THIS IS USUALLY MOST ECONOMICAL COMPROMISE.
BRUSH SHIELD
COMMON GROUND
RING SHIELD
ARRANGEMENTS SHIELDING BOTH SLIP RINGS AND BRUSHES GIVE GOOD PERFORMANCE BUT ARE COMPLICATED. THEY ARE OFTEN BULKY AND USUALLY COST MORE - MAINTENANCE IS OFTEN MORE DIFFICULT.

Fig 13 Methods of Using Electrostatic Shields

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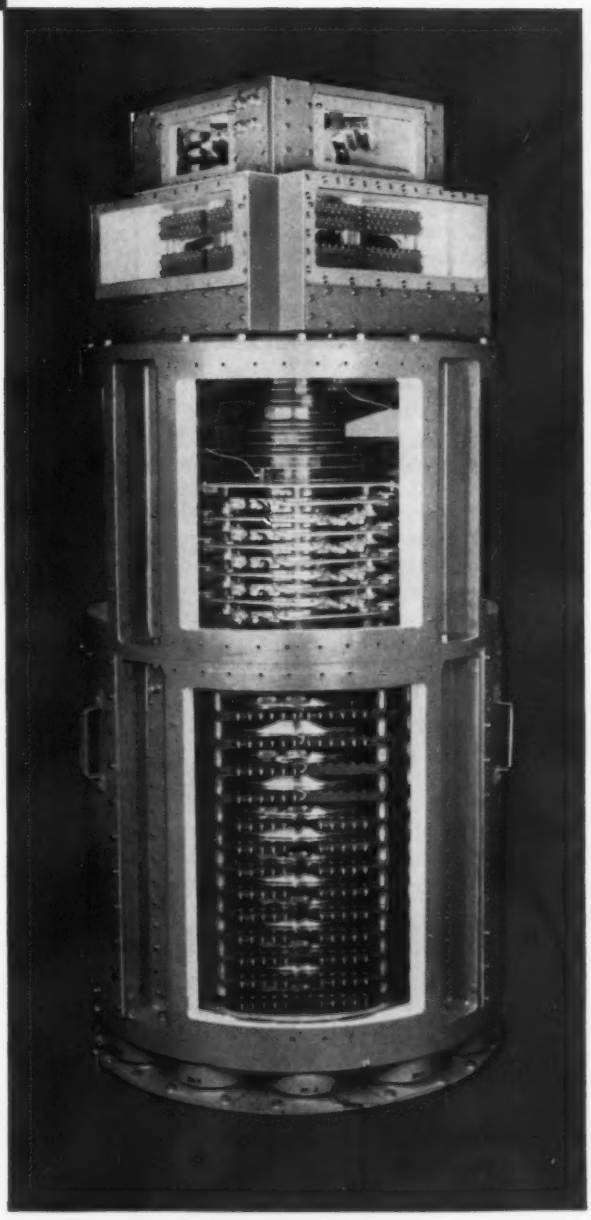

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which have, in addition, a small amount of molybdenum disulphide added are among the better performing materials at temperatures around +250°C. Such performance is far from ideal. Ceramics are ideal insulators but are difficult and costly to work with.

The problems at high temperature are of course aggravated by such things as high speed and high current. Much research in materials is needed before satisfactory high temperature rotary electric dc couplings are available.

OPERATION AT LESS THAN ONE ATMOSPHERE

When any two metal surfaces are slideably engaged at a normal sea level atmosphere, a considerable lubrication results, both from the gases of which the atmosphere is composed and from the absorbed moisture. This fact first came to critical notice with the greatly reduced brush life on aircraft generators. It was found that graphite tended to lose its lubricating qualities at the higher altitudes. For this reason, graphite lubricated brushes for use between 10,000 and 50,000 feet are chemically treated to provide a substitute for these elements that support the lubricating qualities of graphite.

THE OUTER SPACE PROBLEM

Where rotary electric couplings are required to operate at 10^{-9} millimeters of mercury and less, the entire picture changes. Materials that are subject to the transient type of cold welding in a normal earth atmosphere, referred to as galling, will weld tightly together at such vacuums. The continuous surface dissipation due to sublimation insures an absolutely uncontaminated condition between mating surfaces. At vacuums of the order of 10^{-15} millimeters of mercury, such as are encountered well out from the earth, the use of such devices becomes critical. Contacts are not the only problem. Insulating materials made of plastics are subject not only to sublimation but to structural changes due to the various radiations involved.

At the present time, some of the thermosetting epoxies have good promise for extended life in hard vacuum.

At least two separate organizations have developed mono-molecular lubri-

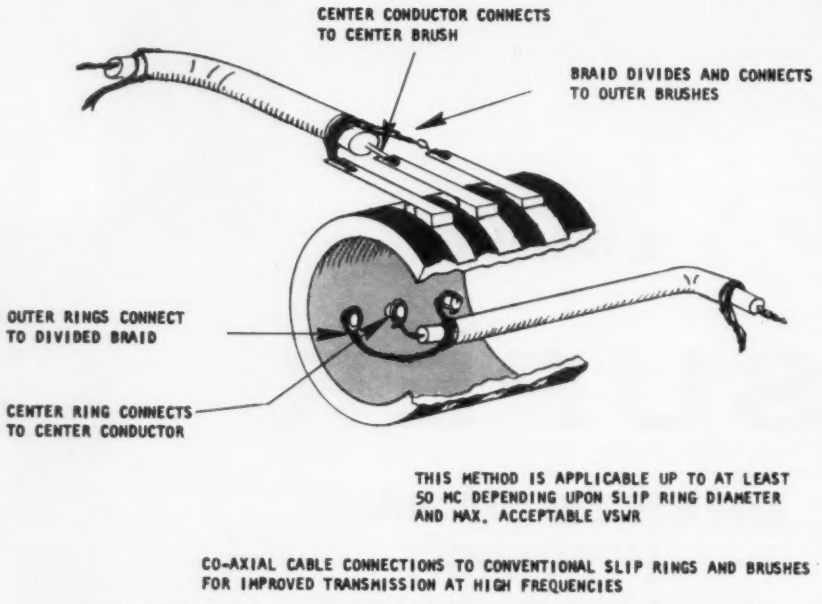
CENTER CONDUCTOR CONNECTS TO CENTER BRUSH
BRAID DIVIDES AND CONNECTS TO OUTER BRUSHES
OUTER RINGS CONNECT TO DIVIDED BRAID
CENTER RING CONNECTS TO CENTER CONDUCTOR
THIS METHOD IS APPLICABLE UP TO AT LEAST 50 MC DEPENDING UPON SLIP RING DIAMETER AND MAX. ACCEPTABLE VSWR
CO-AXIAL CABLE CONNECTIONS TO CONVENTIONAL SLIP RINGS AND BRUSHES FOR IMPROVED TRANSMISSION AT HIGH FREQUENCIES

Fig 14 H.F. Slip Ring Arrangement using General Purpose Slip Rings

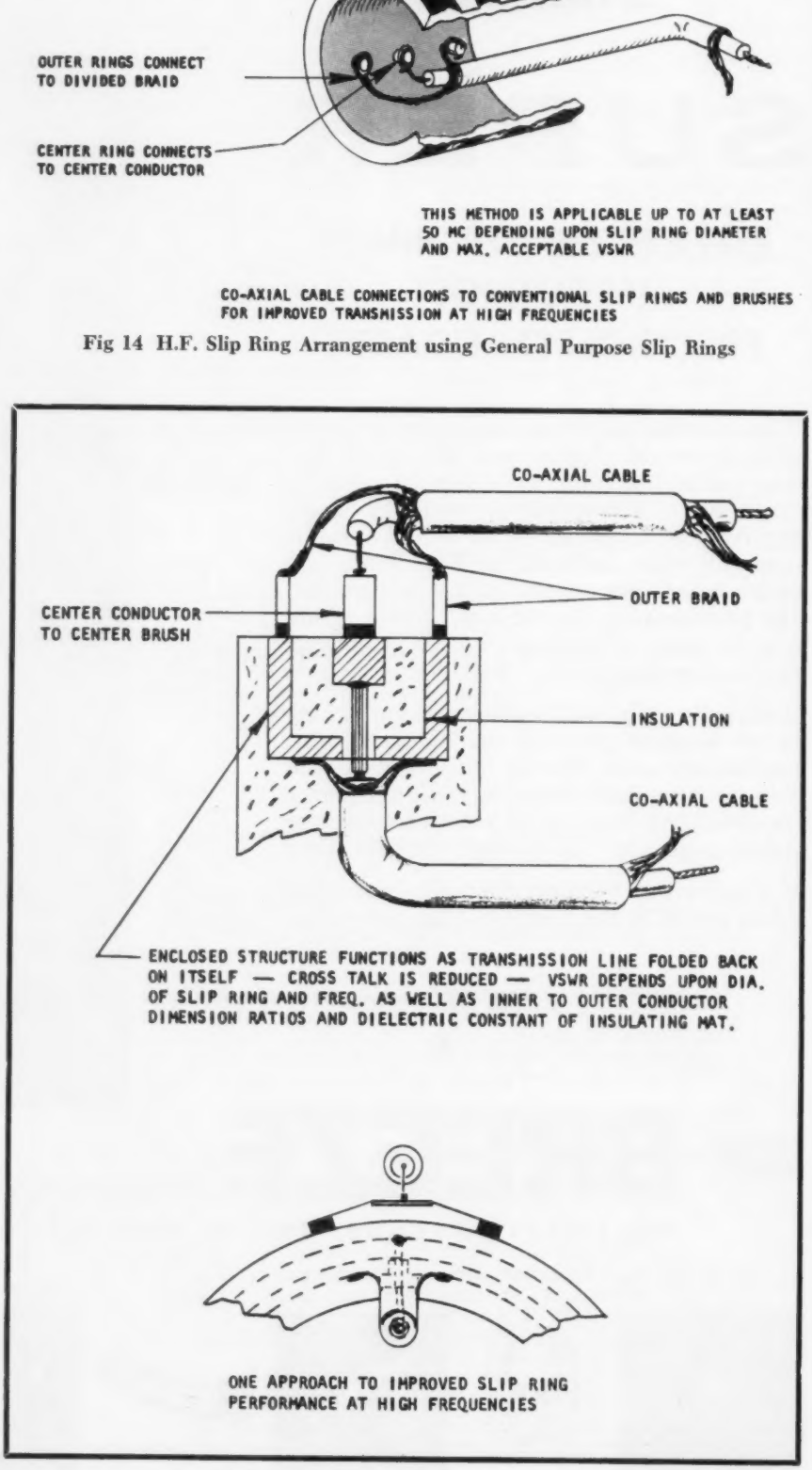
CO-AXIAL CABLE
CENTER CONDUCTOR TO CENTER BRUSH
OUTER BRAID
INSULATION
CO-AXIAL CABLE
ENCLOSED STRUCTURE FUNCTIONS AS TRANSMISSION LINE FOLDED BACK ON ITSELF — CROSS TALK IS REDUCED — VSWR DEPENDS UPON DIA. OF SLIP RING AND FREQ. AS WELL AS INNER TO OUTER CONDUCTOR DIMENSION RATIOS AND DIELECTRIC CONSTANT OF INSULATING MAT.
ONE APPROACH TO IMPROVED SLIP RING PERFORMANCE AT HIGH FREQUENCIES

Fig 15 Slip Rings as Transmission Lines

cating films which are being tested and which have promise of at least limited period lubrication.

The metal rhenium in combination with fine silver using molybdenum disulphide as a dry lubricant has been tested favorably for certain hard vacuum applications. Part of the job of research and development is hampered because of the difficulty of creating vacuums of better than 10^{-9} mm hg in chambers of useable size and the difficulty in instrumenting them. Recoverable satellite capsules may be the eventual answer to such testing.

THE HIGH FREQUENCY PROBLEM

Advanced system designs in communication and instrumentation are focusing greater attention on the transmission of frequencies above 30 megacycles through rotating joints. This is not difficult when only one conductor is involved since a single co-axial line joint may be made with practically no discontinuity. Where two or more lines are involved, the problem becomes much more difficult. The regular slip ring technique may be used with good results if the ratio of a quarter wave length of the frequency to be transmitted to the slip ring diameter may be held to 50:1 or better. Voltage standing wave ratios of 1.05:1 or better may be accomplished with refinements of the configuration shown in Figure 14.

Since the rotating rings are usually connected to the conductor at one spot on the circle, there will be a cyclic variation of the inductance with rotation as well as capacitance changes which will produce an amplitude change in the signal output. This condition, of course, represents a change of impedance and also will affect the phase angle of any transmitted energy in accordance with rotation. The design trick is to minimize all of these effects. The stability and dielectric constants of the material used for ring spacers and/or insulators merits more attention for high frequency service than for dc and low frequency use.

Where the diameter of the slip ring cannot be designed small with respect to a quarter wave length, it is necessary to make the slip ring and brush arrangement appear as a part of the transmission line. In this instance, as in the former case (Figure 14), the line impedance should be kept low. A figure of 50 ohms is more or less standard. No manufacturers supply standard slip-ring devices of this sort at the present time although a number of units have been built for specific applications. Where such devices are used, the VSWR of the transmission system sections which the HF rotary electric coupling interconnects must have a very low VSWR also.

Figure 15 shows one approach to the problem. This is, at best, a compromise. At least one slip ring manufacturer is developing new design techniques in this field and improved devices are expected to be available in 1962. • • •

SLIP RING RELIABILITY

In a paper titled "Reliability Aspects of Slip Rings" prepared for a slip-ring seminar at Electro-Tec Corp., K. R. North of that Company discusses some of the critical areas in design of slip-ring assemblies. Here are some of the problem areas which he says should be better understood by engineers who specify slip-rings.

Common Causes of Slip Ring Failure

Extensive tests have revealed that some types of slip-ring failure are more prevalent than others and that many of these failures may be sufficient to render the equipment useless. In many instances, the life of the equipment could have been extended by a proper design or use of materials more suited to the application.

An understanding of the causes of these failures and how they can be avoided is instrumental in specifying and designing reliable slip-ring assemblies.

OPEN CIRCUIT — EXTERNAL

External opens are usually either lead or brush failures. Lead failures are normally caused by over stressing or over flexing of external leads and are usually more prevalent in slip rings incorporating 30 gage or smaller leads. Recently some slip-ring users have been specifying stranded leads in all miniature applications. They should realize however that while stranded leads will stand more flexing before failure than solid conductors they may be weaker in tensile strength than the equivalent gage solid lead. The breaking strength for an average 32-gage solid-copper conductor is less than two pounds. The user should also be cautioned that one or more strands of a stranded lead may be easily broken when external connections are being made or during normal use. While this condition is not usually detected by routine continuity tests it will appreciably affect the impedance and current carrying capacity of the circuit.

Open circuits due to brush failures are usually the result of excessive wear or bent or broken contact arms and springs. It is good practice when possible to check brushes periodically for wear, pressure and alignment on slip rings used in continuous operation for extended lengths of time. Recommended pressures, checking procedures and replacement intervals may usually be obtained from the manufacturer. The manufacturer should be consulted in all cases where readjustment or replacement of brushes appears necessary since many of the small precision brushes must be assembled and preset at the factory.

Internal open circuits are usually caused by bond separation between lead and ring or ring terminal. This failure usually is the result of excessive stressing of leads and is more prevalent in assemblies where leads are not molded or imbedded in a plastic overcast. Sometimes corrosion at an internal bond connection will be sufficient to cause an open circuit. This type of failure is usually gradual and preceded by an increased resistance in the circuit. Corrosion may be enhanced by the penetration of any corrosive salts, solutions or gases between the insulation and conductor of a lead. Improper soldering, fluxes such as acid or activated solutions are common causes of corrosion that sometimes travels several feet within an insulated lead. For this reason extreme care in cleaning and inspection is made on all internal bonds during manufacture to eliminate the possibility of corrosion. With reasonable care when making external connections there is little danger of corrosion starting at these junctions.

ELECTRICAL SHORTS

Shorts may be caused by a build up of worn contact material between adjacent ring or brushes but are more often caused by damaged lead insulation. This is usually the result of excessive temperature exposure to lead insulation when solder connections are being made. Nylon and some plastic insulations usually become brittle when overheated and will crack away after slight flexing. Teflon insulation is subject to abrasion and care should be taken in making connections to avoid lead contact or abrasion against sharp surfaces. Emphasis on miniaturization has forced use of minimum insulation thicknesses resulting in fragile components. Hence, care must be taken to protect these components both during manufacture and in final systems assembly.

INSULATION BREAKDOWN

Insulation breakdown usually results in leakage or arcing of electrical

current through the dielectric between rings or leads. This type of failure is caused by excessive voltages, including repeated test voltages, cracking of dielectric material through excessive shock or heat, or deposition of moisture or foreign material on the surface of ring barriers. Resistance to hi-pot failure may be increased through design by choosing plastics with a higher dielectric strength and by incorporating wider barriers in the assembly.

ELECTRICAL NOISE

While noise may occur through thermal effects, junction effects, sliding contact effects and piezoelectric effects, electrical noise in slip rings is predominately the result of resistance changes between a ring and sliding contact caused by minute variations in contact area and pressure as the ring rotates. Noise is usually read as the peak to peak voltage fluctuation observed on an oscilliscope connected across the brush ring contacts when the slip ring is rotated with a measured amount of current flowing through the circuit. Electrical noise increases with surface speed, and decreases with higher brush pressures. It is also influenced by vibration, the material and finish of rings and brushes, and the concentricity of the rings. Under normal operation noise generally increases with wear until eventually it interfers with the transmitted signal.

STRUCTURAL FAILURE

Bearing failures may be caused by excessive speeds and temperatures, insufficient lubrication, vibration, dust or foreign material, improper drive couplings, and by running the bearings beyond their normal life. Most premature failures occur because of overloading due to improper alignment of external drives to the slip ring shaft. A flexible coupling is always recommended where possible on this type of assembly.

Torque failures are usually the result of either bearing friction or excessive brush friction. Some slip rings have failed in operation due to bearings freezing at sub zero temperatures. This condition can be avoided by proper selection of bearings for the low operating temperature. Bearing seals are also a source of high torque on certain assemblies. Brush friction torque can be reduced by reducing brush size and pressure and proper selection of contact materials.

HIGH TEMPERATURES

Overheating in itself is not a failure, but many slip ring failures are the result of overheating. Causes of slip ring heating are: excessive speeds, excessive brush pressures, high bearing loads, excessive currents, high ambient temperatures.

Overheating of an assembly may cause these failures: excessive torque, differential expansion of plastics and metals causing misalignment of brushes, overstressing and breaking plastic barriers, cracking of dielectric causing hi-pot breakdown, leakage or broken leads, warping of brush springs or contacts resulting in changes of pressure and excessive noise, excessive wear on contacts and bearings thus reducing life expectancy.

Slip rings can be designed to operate under certain extreme temperature conditions. All conditions of expected operation should be given the manufacturer in order to obtain the proper design and recommendations for a particular application.

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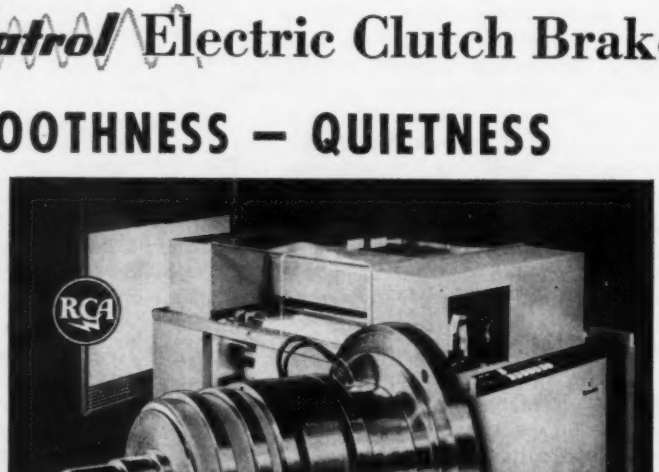

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Test Specifications and Design Limitations

In defining the requirements of a slip ring for a particular application, the customer usually specifies the materials and performance characteristics he feels the application demands. But because of uncertainties about operating conditions and limited knowledge about the capacities of materials and procedures of testing he often calls for over design in some specifications, and completely neglects other design aspects vital to reliable performance. In the following paragraphs, Mr. North provides information on slip-ring test procedures and design limitations that the customer should know.

ELECTRICAL NOISE

Noise is probably the most misinterpreted and least understood of all slip ring performance specifications. Since there is no standard method for specifying it noise has been defined in many ways. The most common procedure is to list a maximum peak-to-peak voltage fluctuation at a given current input. Noise may also be expressed as a maximum change in resistance of the circuit – a more desirable method from a test viewpoint. Too often a customer will specify a maximum noise level as a voltage requirement without stating the signal or test current. Since the noise is directly proportional to the signal current it is vital that realistic current values be given.

Precision slip rings operating at moderate speeds can be designed for a maximum noise of about .005 ohms (5 milliohms). Based upon an assumed constant current this would be equivalent to 50 microvolt peak-to-peak signal across the contacts with a 10 milliampere current flowing through the circuit. Where noise requirements are more stringent or where surface speeds are excessive, special designs are usually necessary. These include parallel brush contacts, special brush and ring materials, closer tolerances on concentricities and finishes of rings and specially tuned brush arms to eliminate spring resonances at any vibration frequency.

The following suggestions and recommendations are offered as a guide to users in writing noise specifications for slip rings:

- Specify noise as a resistance change when possible.
- Remember that a noise specification less than 5 milliohms is difficult to maintain on average slip rings without added costs for special design and materials.
- When specifying a noise limit as a voltage be sure to state the signal test current.
- When specifying noise as a maximum voltage it is recommended that a low limit of at least 20 microvolts be observed because of interference limitations of test circuits such as preamplifier noise, radio and line pickup, etc.
- When possible, state frequency range necessary for critical noise specifications. In some applications noise is not objectionable in certain frequency ranges, or may be filtered out of sensitive signal circuits.

CROSS TALK

Electrical noise is often confused with cross talk. Cross talk is the electrical interference between two circuits commonly expressed as a decibel ratio of the signal voltage in a circuit to its induced voltage in another circuit. The interference may be caused by electrical leakage through the insulation or capacitive and inductive coupling between the conductors. Cross talk is dependent upon the spacing and length of conductors, the resistivity and dielectric constant of the insulation and the general configuration of the slip ring. It is also dependent upon the frequency of the signal, external circuit impedance and ambient environmental conditions of operation. Cross talk in high frequency circuits is principally a function of ring to ring capacitance. This capacitance normally will be between 5-200 micro-microforads depending upon the particular design.

The following signal versus cross talk values show typical frequency relationships established for slip rings of proper design under optimum conditions of operation and circuit isolation.

150 KC	70 - 80 decibels
30 MC	60 - 70 decibels
60 MC	40 - 50 decibels

INSULATION RESISTANCE

Insulation resistance is generally measured from each circuit of a slip ring to all other circuits in parallel and to the shaft or housing of the assembly. Readings are taken with a megohmmeter at usually 50 or 500 volts dc. It is dependent upon the length and spacing of conductors, the resistivity of the insulation, voltage, temperature and humidity conditions at which measurements are made. Many filled and laminated plastics are subject to absorption and retention of moisture and often present a critical variable in resistance testing under high humidity conditions. Condensation is often difficult to control above 95% relative humidity and extreme care must be exercised in performing valid tests at near saturation conditions. Generally, slip rings are designed to exceed 100 megohms insulation resistance at 60% R. H. and 500 vdc.

DIELECTRIC STRENGTH

Dielectric strength is measured by impressing a specified voltage across adjacent circuits of a slip ring. The voltage may be dc or 60 cycle ac. Failures may be specified either as an arc discharge between the circuits (usually destructive) or as a maximum current leakage rate (non-destructive). Hi-pot testers may incorporate indicator lights for leakage or current limiting relays to open the circuit when leakage exceeds a fixed or controlled value.

Some dc hi-pot testers are equipped with sensitive microammeters to measure leakage while voltage is increased. There is sometimes confusion as to the difference between an insulation test and a hi-pot test. While both are related to the dielectric properties of the insulation the difference may be explained as follows:

"Insulation resistance is a measurement of the total resistance between two insulated circuits while a hi-pot breakdown is a measurement of the dielectric strength at the weakest point between the two circuits." This breakdown generally occurs across the narrowest air gap or along the surface of the insulation between rings or exposed terminals of a slip ring. Since the dielectric strength of most slip ring plastics are in the order of three to six times that of air, high voltage designs sometimes incorporate raised ring barriers to increase air gap distances effectively. Surface condensation or contamination between rings serve to create potential breakdown paths and effectively reduces the dielectric strength of the air gap. Air at standard conditions has a dielectric strength of approximately 60 volts per mil. Miniature slip rings are usually designed to meet a 500 volts ac breakdown test with a one-half milliampere leakage designated as failure. Larger assemblies incorporating ring barriers over .040" wide usually are tested at 1000 volts. Special slip rings have been designed to withstand voltages as high as 75-KV.

In the interest of reliability the slip-ring user should be aware of the fact that repeated hi-pot tests may reduce the dielectric strength of some insulating material by partial breakdown from undetected current leakages through or on the surface of the barrier. The number of hi-pots should be kept to a minimum in all non-destructive test programs. • • •

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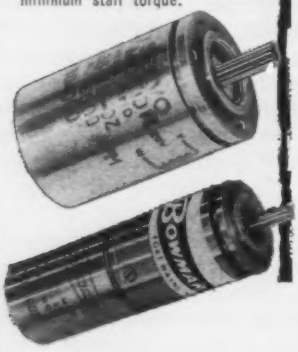

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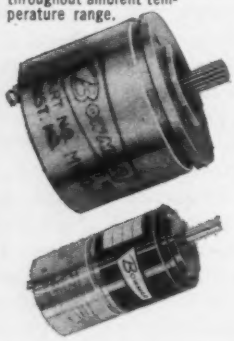

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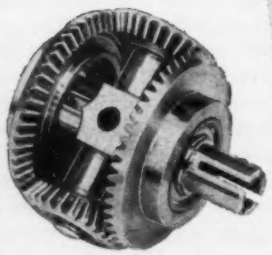
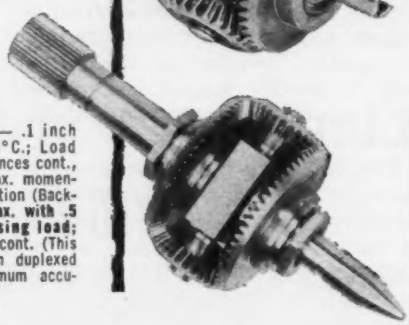


TYPE X-1943

Starting Torque — .1 inch ounce max. at 25°C.; Load Torque—25 inch ounces cont., 75 inch ounces max. momentary; Max. Lost Motion (Backlash)—**1.5 min. max. with .5 inch ounce reversing load;** Speed—700 r.p.m. cont. (This type equipped with duplexed bearings for maximum accuracy and rigidity).



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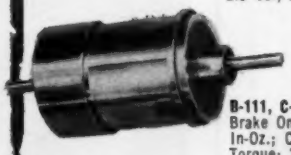
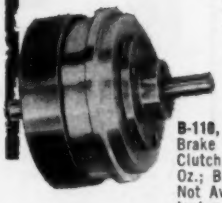


B-111, C-111, BC-111
Brake Only Torque: 16 In-Oz.; Clutch Only Torque: 32 In.-Oz.; Brake-Clutch Torques; 16 In.-Oz.; Length: 1.485 Inches; Weight: 5 Oz. Approx.

'PANCAKE' SIZE 11



B-110, C-110
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NEW TRANSISTOR LINES 357

are available from National Semiconductor Corp., Danbury, Conn. In addition to a new silicon epitaxial series of NPN high-speed switching devices featuring low saturation voltages, high breakdown voltages and low output capacities, the company also has NPN small signal silicon transistors (Series NS475-80) in the subminiature TO-46 "pancake package." One third of the height of the TO-18 package, the TO-46 design simplifies circuit design while maintaining the same diameter for direct replacement of the TO-18. NPN medium power (500 milliwatts) transistors, designed for input stages where low noise, high gain and low leakage currents are required, is available in the TO-18 package. The new series, NS430-38 is beta spec'd at 5 different collector currents.

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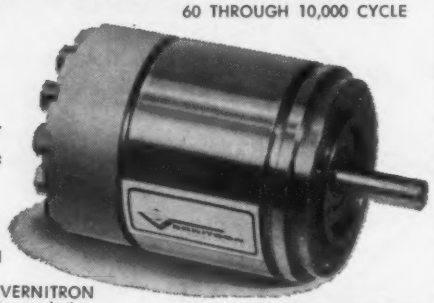

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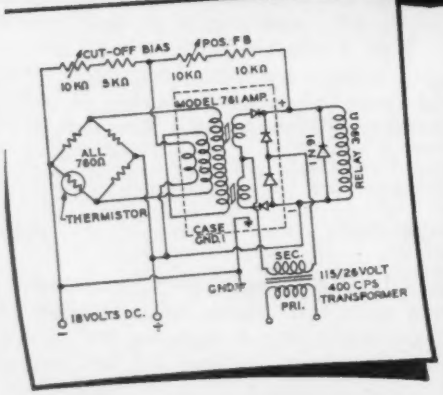

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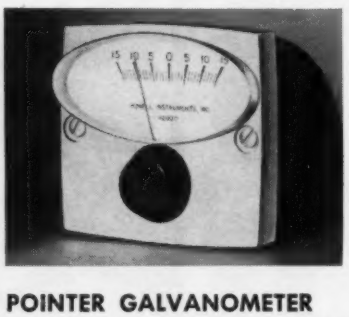
CIRCLE NO. 50 ON INQUIRY CARD

NEW COMPONENTS

MOLDED CARBON POT 383

(single-turn trimmer) provides noise free, stable construction because the resistance element is molded into the insulating base structure. In the design by Centralab, Electronics Div. of Globe-Union, Inc., Milwaukee, Wisc., the carbon brush under high tension allows for precision adjustment of the resistance. The pot has a screw-actuated lock, is resistant to shock, vibration and acceleration, and can be encapsulated in a rigid resin without damage. In the unenclosed state, its construction is the least affected by humidity of any unsealed variable resistor according to the company. Designed for use in printed circuit boards, the unit is 19/32" in dia. and 11/32" deep from the mounting surface, and mounts in three 1/16" holes in the circuit board. Resistance, from 500 ohms to 5 megohms, linear taper, are available.



POINTER GALVANOMETER 334

A modification of a light-beam galvanometer designed for use in panel or portable instruments of the null type is a taut suspension moving coil type instrument. The suspensions, of 14K gold, terminate in shock mountings. An Alnico V permanent magnet insures highest permanent flux density. Unit has operated satisfactorily in ambient temperatures of −55°C to +71°C. Standard equipment on the unit is a pointer index with zero center 30 millimeter scale. Zero adjusting knob is provided on the face of the instrument. Systems with resistance values from 10 ohms to 1000 ohms are included in the new line and sensitivities from 1.25 microamps to 0.15 microamps per millimeter scale division are available. Howell Instr. Inc., Ft. Worth, Texas.

3-AXIS RATE GYRO 348

is a high resolution, extremely accurate, 3-axis telemetry subsystem for use in spin-stabilized missiles has been developed by Fairchild Controls Corp. of Hicksville, L.I., N.Y. Weighing less than 4 lbs., the self-contained system incorporates 3 rate gyros to telemeter the pitch, yaw and roll of a spin-stabilized missile at spinning speeds of up to 5000°/sec. Made on special order only, have "self-test" capabilities designed into them.

RF CONNECTORS, 352

50-ohm screw-on type, feature flash-power at 70,000′ at 1000 volts min. and reliable performance at 200°C for sustained periods. Design characteristics allows field assembly without tools, and inspection and cleaning without spare parts. Utilizing no rubber plastic boots or compression washers, the subminiature units feature an all metal-to-metal contact to hold the coaxial braid. Immediate delivery on smaller quantities; 30-day delivery on large orders. Micon Electronics, Inc., Garden City, N.Y.

FLEXIBLE COUPLING 382

with metallic bellows as the flexible element couples two shafts in absolute unison without backlash or cyclic angular displacement during rotation. The corrosion resistance nickel bellows flex-element has high elasticity and low hysteresis. Applications of the miniature units include couplings where noise or waver cannot be tolerated and wherever perfect tracking without backlash is a requirement. Standard sizes that are currently available with recommended torque on request. Guardian Industries, Inc., Coupling Div., Michigan City, Ind.

POWER SUPPLY, 380

for rack or bench mounting, features continuous front panel adjustment over the range of 0 of 36 VDC at a maximum output of 3 amps up to an ambient temperature of 50C. Line and load regulation is 0.01%, ripple is less than 0.3 millivolts RMS and output impedance is less than 0.001 ohms. Additional standard features of this "off the shelf" transistor unit are convection cooling, 105 to 125 VAC at 60 to 400 cps input, triple overload and short circuit protection, output meters and adjustments on front panel, and remote load sensing. Kaiser Electronics, Inc., Union, N.J.

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SERVO MOTORS	FRAME SIZE	VOLTS Ø1	VOLTS Ø2	STALL TORQUE	SPEED RPM	STALL PWR/Ø	ACCEL. RAD/SEC²
20D633-2C	8	26	26	.22 OZ. IN.	6200	2.5W	106,000
20D633-4C	8	26	36 CT	.22 OZ. IN.	6200	2.5W	106,000
20D632-4C	8	26	36 CT	.35 OZ. IN.	6200	3.1W	99,800
20D627-2C	8	115	115/57	.33 OZ. IN.	6200	3.5W	98,000
20D603-2C	11	115	115/57	.60 OZ. IN.	6200	3.5W	43,300
20D603-4C	11	115	36 CT	.60 OZ. IN.	6200	3.5W	43,300
20D590-2A	15	115	115/57	1.3 OZ. IN.	4800	6.2W	27,800
20D612-2C	18	115	115/57	2.3 OZ. IN.	4800	9.1W	31,000

MOTOR TACHS	FRAME SIZE	VOLTS Ø1	VOLTS Ø2	TACH. VOLTS	STALL TORQUE	SPEED RPM	V/1000 RPM	TOTAL NULL	ACCEL. RAD/SEC²
20D628-2C	8	115	115/57	26	.33 OZ. IN.	6200	.20	.019V	75,800
20D631-4C	8	26	36 CT	26	.35 OZ. IN.	6200	.20	.019V	80,500
20D634-2C	8	26	26	26	.22 OZ. IN.	6200	.20	.019V	75,000
20D634-4C	8	26	36 CT	26	.22 OZ. IN.	6200	.20	.019V	75,000
20D604-2F	11	115	115/57	115	.60 OZ. IN.	6200	.500	.019V	32,600
20D604-4F	11	115	36 CT	115	.60 OZ. IN.	6200	.500	.019V	32,600
20D593-2A	15	115	115/57	115	1.3 OZ. IN.	4800	3.1	.019V	17,500
20D614-2C	18	115	115/57	115	2.3 OZ. IN.	4800	3.1	.019V	25,900

INERTIA DAMPED	FRAME SIZE	VOLTS Ø1	VOLTS Ø2	STALL TORQUE	STALL POWER	SPEED RPM	DAMPING
20D618-2B	8	115	40/20	.30 OZ. IN.	3.5W	6200	40 DYNE CM
20D605-2D	11	115	115/57	.60 OZ. IN.	3.5W	6200	100 DYNE CM
20D613-2C	18	115	115/57	2.3 OZ. IN.	9.1W	4800	750 DYNE CM

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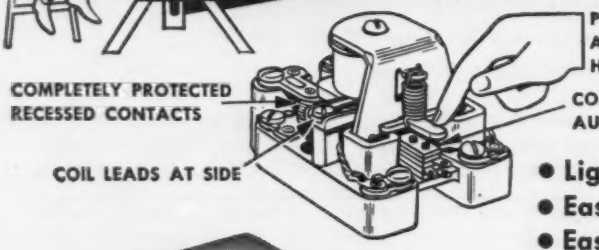
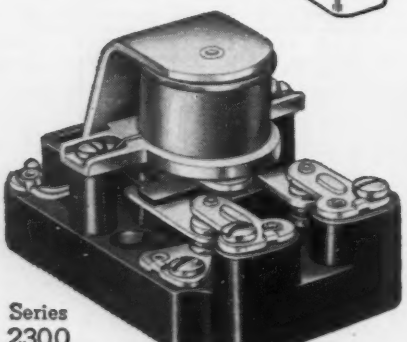
CIRCLE NO. 52 ON INQUIRY CARD


PUSH TO TEST AT REAR AWAY FROM ALL HOT CONTACTS
COMPLETELY PROTECTED RECESSED CONTACTS
COMPLETELY PROTECTED AUXILIARY SWITCH
COIL LEADS AT SIDE

- Lightweight
- Easy to Test
- Easy to Service
- Easy to Mount



A quick check of the unique features incorporated in this totally new Guardian Power Relay should attract and intensify the interest of engineering specialists who are responsible for the dependable performance of power relay controls.

1. **Inverted Coil Construction protects armature and contacts to insure long life, reliable electro-mechanical operation.**
2. **Contacts (D.P.D.T.) U/L rated for 15 amperes at 115 V.A.C. non-inductive, or 1 H.P. at 115/230 volts, 60 cycles.**
3. **Screw Type Terminals easily accessible for top or bottom connections.**
4. **Recessed Auxiliary Switch up to S.P.D.T. rated at 125 volt amperes Pilot duty 115/230 V.A.C., 60 cycles, or 10 amperes at 115 V.A.C. non-inductive.**
5. **Armature Extension permits manual circuit testing.**

Voltages: 6,12,24,115 and 230 V.A.C., or 6,12,24,110 and 220 V.D.C.

Size: 3 5/16" x 2 1/2" x 2 1/16". Shipping Weight: 8 ounces.

Mounting: Two 3/16" holes on 1 7/8" centers. Low Priced.

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CIRCLE NO. 53 ON INQUIRY CARD

NEW COMPONENTS

RELAY-MODULE 403

for easy installation in printed wiring systems uses dry-reed switch contacting element to provide high speed and long life. Unit consists of single-pole, single-throw, normally open, reed switch rated at 12 volt-amps up to 250 volts AC, resistive load. Up to 12 switches can be operated by same coil. Operating coil is wound on nylon bobbin in whose square ends connecting pins for both the coil and switch are secured. Finish is a winding of acetate thread coalesced to form a dust-proof protective seal. Size: 3/8" sq. x 7/8" long. Operating time: from 1.5 to 3 milliseconds at coil power of 0.1 to 0.4 watts. Coils can be furnished for operation at 6, 12, 24, 32 04 48 volts DC. D. Randall Co., Westerley, R.I.

MICROWAVE BANDPASS 410

qualified under applicable government specifications for military environments, are supplied to any designated center frequency between 2000 and 4000 mc., with a bandpass width of from 40 to 80 mc required. Low insertion loss and low ripple content along with good temperature compensation assure maximum performance from the 4-section, tuned element device. Coupling to an additional output from which the bandpass can be monitored is factory adjusted for between 10 and 20 db down from the main channel and terminates internally in a 50 ohm resistor for matching into a detector, signalling circuit or measuring device. Ten oz. filter has housing of high silicon, silver plated brass casting with soldered cover and components. Microwave Div., Instrument Systems Corp., College Pt., N.Y.

3-AMP POWER TRANSISTORS 411

have low I_{CBO} due to small junction area of 50μ . A maximum of collector-base voltages of 2 v, and 5 ma maximum at rated collector-base voltages ranging from 30-90 volts (at +71C). Maximum junction-to-case thermal resistance is 1.2C/W compared to 1.5-2.5C/W of competitive types, according to the company. Series includes 5 units with a dc current gain of 30-60 and an additional five transistors with gain ranging from 50 to 100, at collector currents of 0.5 amps. Tests per MIL-S-19500 and other shock and vibration tests. Motorola Semiconductor, Phoenix, Arizona.

PAPER-TAPE REELER 407

handles tape speeds up to 40 ips with reels of 5″ to 8″ dia. Bi-directional unit imposes no restrictions in selection of tape materials for prevention of tape materials for prevention of tape damage or breakage. Spring loaded dancer arms provide positive on-off control of tape feed, maintain constant tape tension and tape storage and prevent tape spillage from broken or end-of-tape conditions. Size for standard rack mounting: 19″ W x 10½″ H x 11¼″ D max, with 2¼″ front panel extension. Weight: 45 lbs. without reel. Omnitronics, Inc., Philadelphia, Pa.

GYRO SUPPLY UNIT 408

contains its own voltage regulation systems making it independent of the variations in the input supply low characteristics and environmental conditions. Tuning fork achieves frequency regulation of ±0.01% at 400 cycles. Packaged to meet customer requirements, 3-phase unit delivers 30 volts rms, with accuracy of ±1% line to line. It operates at 27 volts ±3 volts DC, at 1.5 amps maximum delivering 7.5 volt-amps per phase maximum and 3.3 volt-amps per phase normal. M. Ten Bosch, Inc., Pleasantville, N.Y.

LOW-PRICED BRAKE, 342

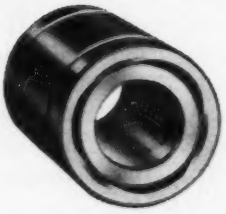
for stopping overtravel in sub FHP motors used in mechanisms requiring instant stop, has a braking torque of 2 to 4 in. lbs. for shafts up to ⅜″. Brake band almost completely encompasses the drum. Constant duty solenoid furnished in ac up to 230 v or dc as low as 12 v is connected parallel with the motor. Actuating the motor causes the solenoid to depress a pivoting arm that loosens the brake band. When power to motor is cut, solenoid releases pivoting arm and stainless steel spring pivots arm upward tightening brake band against shoe. Midwest Automatic, Inc., Des Moines, Iowa.

LIMIT SWITCH 354

based on a solid state design that contains no make or break electrical contact, may be used in any application where roller-lever actuated switches are now employed. High reliability makes it useful for position indicating and limiting, safety interlocks and similar applications. Texas Instruments, Inc., Houston, Texas.

CIRCLE NO. 54 ON INQUIRY CARD →

...*for* **MINIATURIZATION**



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NEW... DETAILED DATA ON SERVO MOTORS

Here's information you can use to increase speed and accuracy in high precision control and measuring equipment . . . 4 fact-filled pages on Holtzer Cabot's line of R-24 Servo Motors.

Contains 3 sets of speed-torque, performance curves: (1) For four different stator stackings with 115V on both windings. (2) For four different stackings with 115V on fixed winding and 200V on control winding. (3) For 0.7″ of stator stacking with 115V on fixed winding and 200V, 100, and 50 on control winding. Gives additional data such as starting voltage, stall torque, rotor inertia, acceleration at stall, etc.

The R-24 Line has stator cores of 2.4″ diam., available with stacking lengths of 0.5″, 0.7″, 1.0″ and 1.4″. Models with or without gear trains. Send for your free copy of Bulletin MO-3.7A. Write: Holtzer-Cabot Motor Division, 125 Amory Street, Boston 19, Massachusetts.

HOLTZER NP CABOT
MOTOR DIVISION
National Pneumatic Co., Inc., Boston 19, Mass.
CIRCLE NO. 55 ON INQUIRY CARD

NEW COMPONENTS

PRECISION RESOLVERS 404

have highly stable transformation ratios without requiring a bulky booster amplifier for temperature compensation. Transformation ratios are ±0.5% for size 8, ±0.2% for size 11 and ±0.15% for size 15 from room ambient value over −55C to +125C temperature range. Maximum length is only 1.750″ for size 8, 2.062″ for size 11 and 1.798″ for size 15. Designed for military, industrial and commercial computing systems, units are manufactured entirely from corrosion resistant materials, housed in stainless steel and meet high humidity conditions. John Oster Mfg. Co., Avionic Div., Racine, Wisc.

DIGITAL SWITCH, 400

designated "Decaswitch", occupies a minimum space and can be stacked up to 15 sections in a panel slot only 8″ x 1-9/16″. "Decaswitch" sections are available in single pole 10-position, single pole 11-position, plus/minus, binary and 2-pole, 5 position models. Switch contacts are gold plated and feature low resistance, yet have smooth positive clock action. Individual sections interlock, assuring positive self-alignment when arranged in stacks. Styled in a molded, gray housing with white numerals on a black background the unit is suitable for incorporation into a wide variety of computers, meters, power supplies, decade boxes and other applications requiring selection or conversion. In-line digital presentation for easy read-in or read-out is a feature of this flexible component. Siegler Corp., Magnetic Amplifiers Div., New York, N.Y.

SILICON TUNNEL DIODES, 405

featuring peak current values up to 4 amps provide significant reductions in circuit complexity and offer high efficiencies in power supply regulators, overload protection circuits, converters, surge detectors and computer circuits. Designated types HT-25, HT-26 and HT-27, the units have output voltages up to 0.8 volts and typical switching times of 5 nanoseconds. Peak current tolerances are ±10% with a temperature coefficient of ±0.04%/C. Operating and storage temperature range is −85C to +200C. Special units are also available for applications requiring other peak current values or tolerances in the 0.0001 to 5 amp range. Hoffman Semiconductor Div., El Monte Calif.

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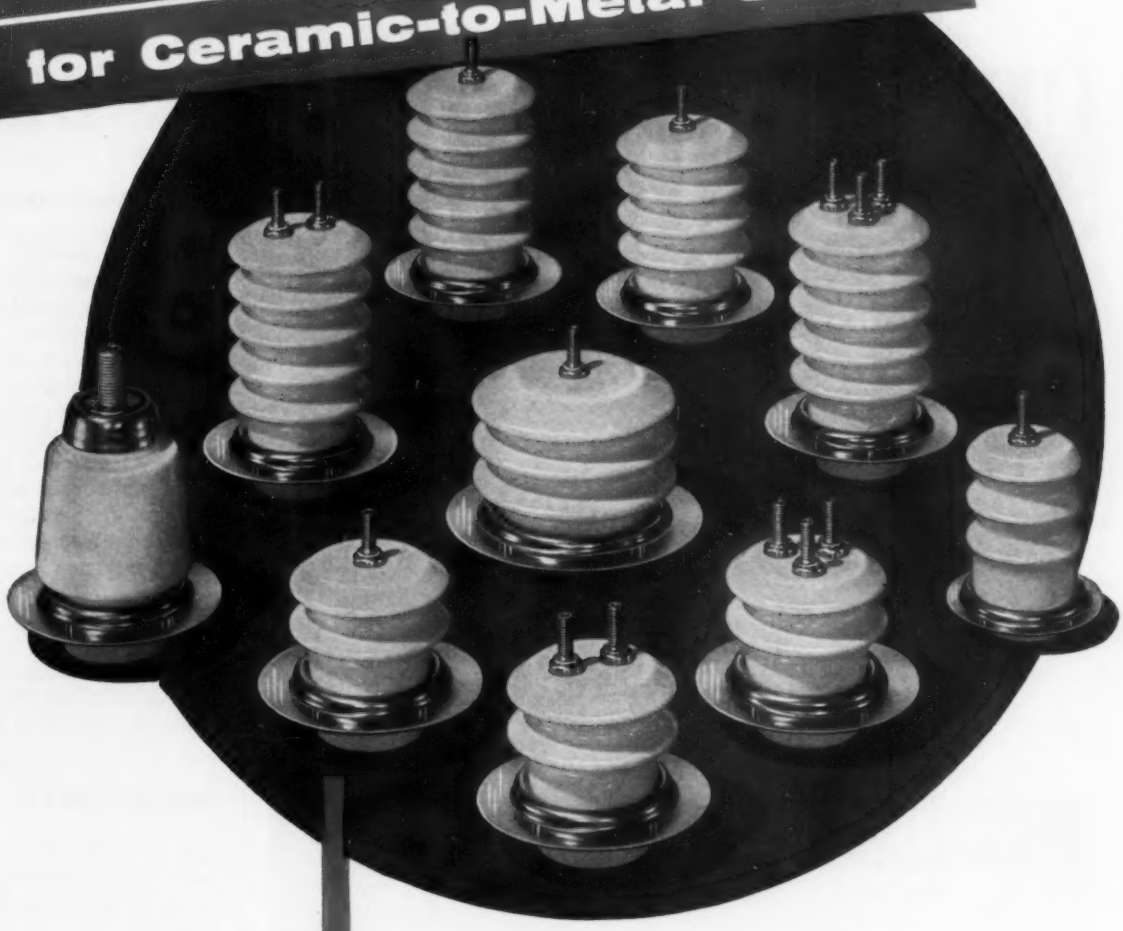

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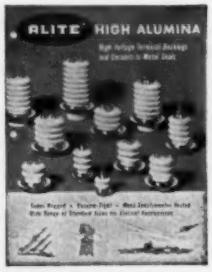

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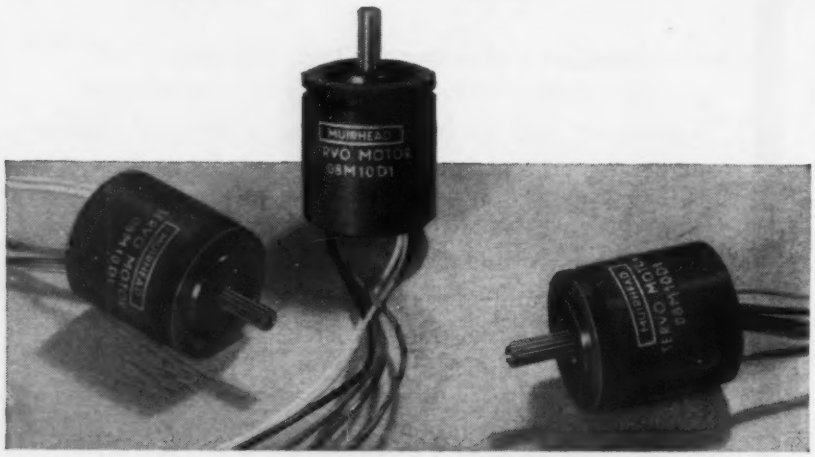
CIRCLE NO. 56 ON INQUIRY CARD

SIZE 8 SERVOMOTORS

The Muirhead Size 8 Servomotor, only 0.84″ in length, and weighing only 1.2 oz. reaches a no-load speed above 6,200 r.p.m. and produces a stalled torque of over 0.2 oz. ins. It has a torque inertia ratio exceeding 110,000 rad/sec.².

The Muirhead Size 8 is but one of a series of servomotors available up to Size 18.

Send for your copy of the latest broadsheet containing details of Muirhead Servomotors and Synchros.



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512/3

CIRCLE NO. 48 ON INQUIRY CARD

NEW COMPONENTS

CORRECTION: *Last month, we erroneously reported the O.D. dimensions of a line of instrument bearings as a little above 10 inches – exactly 10 inches off. The only consolation is that an error of that magnitude is easily recognizable. But now that we have our proper bearings, here is a repeat of that announcement.*

INSTRUMENT BEARINGS 311

thin cross sections of new bearings permit never-before design options, according to manufacturer. For applications requiring combinations of bearing dimensions "in-between" dimensions of standard instrument bearings, the new series contain extra-large bore-to-OD ratios. With material of 440C stainless steel and retainers of plastic crown design with lubricant absorption properties, the bearings are manufactured to ABEC Class 5 and better precision standards. Bore/OD combinations offered include: 0.3750″/0.6250″; 0.5000″/0.7500″; 0.6250″/0.8750″; 0.7500″/1.000″. Widths are standard at 0.1562″. New Hampshire Ball Bearings, Inc., Peterborough, N. H.

SENSING RELAY 401

has a continuous output of 12 to 28 vdc. Upon receiving a transient pulse of 100 microseconds or longer duration, the output is changed to a pulse of 0.5 secs. ON, 0.5 secs. OFF, for a period of 10 secs. and then returns to a continuous output. The output circuit is rated at 500 milliamps continuous load. Recycle time is 15 milliseconds. Designed to comply fully with MIL-E-5400C, the assemblies meet specs of MIL-E-5272C for environmental conditions. Assemblies are encapsulated and enclosed in standard MIL type metal enclosures. Accutronics, Inc., Beverly Hills, Calif.

SEMICONDUCTOR SWITCH 402

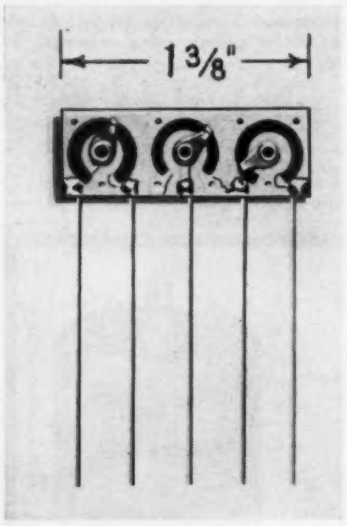
for C-band applications has an average power handling capability of 2 watts at the design frequency of 5585 megacycles, with an insertion loss of less than 2 decibels from 5000 to 5900 mc. Isolation is greater than 50 decibels over the same range, and rise and fall times of the output pulse are less than 0.1 microseconds. The microwave switch has passed all MIL-E-5400 environmental tests. Radio Corp. of America, Burlington, Mass.

SUPERFAST SOLENOIDS **358**

are for use where response time, minute size and/or high force characteristics on reasonable power are determining factors. Under test, units showed response time 1500-2000 micro-seconds while actuating a pound over 0.015" on a power input of 20-25 watts 3-6 vdc. Plotted actuation times are available for different units. Wahlgren Magnetics, Div. of Marshall Industries, Monrovia, Calif.

MINIATURE SLIP CLUTCHES **406**

have application as overload couplings or where a constant torque drive is required. Typical application is a drive coupling in a servo system. Locking-type set screw adjusts torque transmission through a range of from 0 to 4 in.-lbs. Precision Specialties, Inc., Pitman, N. J.



TRIPLE TRIMMER **330**

Production quantities of a subminiature triple trimmer resistor can be had in the 30-40¢ range. Each of the three trimmer resistors in the unit is rated at 0.1 watt. Resistance range is 500 ohms to 5 megohms, linear taper. Additional fixed resistors can be added as an integral part of the device either associated with or independent of the trimmer circuitry. Depending upon value and voltage rating, up to 5 fixed resistors can be incorporated with additional ones included by removing one of the trimmer resistors. Centralab, The Electronics Div. of Globe-Union, Inc., Milwaukee, Wisc.

HOWELL INSTRUMENTS, INC.

MILLI-V-METER—*The Instrument with the Tape-Slidewire—for...*

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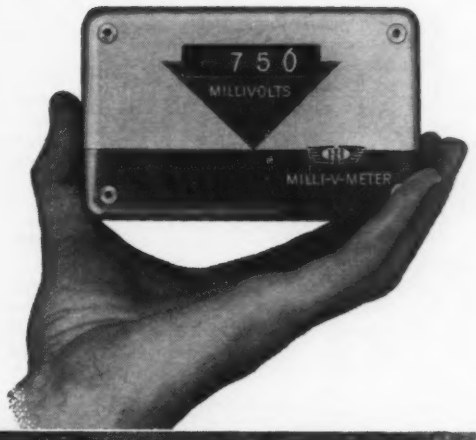
DIGITAL READOUT
ACCURATE TO
0.1%
for all functions of industrial processing plants... 1/20th cubic foot of dynamic measurement.



HOWELL temperature indicator to monitor 48 sensing locations through selector switch circuitry.

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QUALITIES

1) Accuracy 1 part in 1000. Laboratory precision for industry or the military.
2) Compatibility with any transducer—AC or DC.
3) For strain gage, linear differential transformer, thermocouple, thermistor, resistance thermometer, pulse or variable frequency circuits or systems.
4) Operates directly from 60- or 400-cycle power as specified.

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CIRCLE NO. 49 ON INQUIRY CARD

For Your Literature File
NEW CATALOGS

Most of these catalogs contain complete specs, mounting configurations and other details associated with the application of the products described.

Vane-Axial Fans 662

Mounted in any position or installed in ductwork, vane-axial fans can be used for blowing or exhausting to cool heat producing equipment. Fans operate at 3400 rpm on 115 v, single phase 60 cycle current and produce from 50 to 500 cfm at static pressures ranging from 1/3" through 1" wg static pressure. Designed with only 4 major parts — rotor, housing, motor and for some models separately mounted capacitor — the fans withstand, shock and vibration. Fans exhibit the operating noise levels usually found in only custom-built equipment. (8 pp) Joy Mfg. Co., Pittsburgh, Pa.

Light Metals 686

Magnesium, aluminum and titanium are described in booklet which lists comparative values for various metals to assist in the selection of materials. Information is in tabular and graphic form. (44 pp) Brooks & Perkins, Inc., Detroit, Mich.

Contact Protection 998

Use of a capacitor and resistor for contact protection has long been known as an effective means of increasing the life of relay contacts. On grounds of space and cost, capacitor-resistor protection has earlier been confined to contacts subject to extremely severe operating conditions. However, described in a bulletin is an RC unit which is small, robust and inexpensive. It extends the field of RC protection to contacts working under average conditions, according to the manufacturer. Unit is a metallized paper capacitor with the resistance in the metal layer utilized as series resistance to the capacitance. (12 pp) Presin Co., Inc., Santa Monica, Calif.

Snap Action Switches 685

Electrical, electronic and electromechanical applications of snap-action switches are described in a comprehensive catalog. (20 pp) Cherry Electrical Prods. Corp., Highland Park, Ill.

Antenna Instrumentation 955

Condensed catalog describes one source availability for antenna pattern recording, receiving, transmitting and control equipment, antenna positioners, microwave components, auxiliary equipment and recorder supplies. (16 pp) Scientific-Atlanta, Inc., Atlanta, Ga.

Gallium Arsenide 997

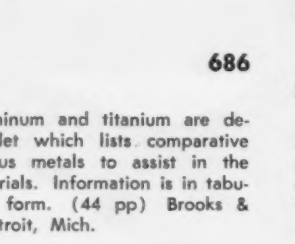
Describing evaluation procedures for use of gallium arsenide, a manual gives detailed methods for measurement of Hall coefficient and resistivity as well as a procedure for the measurement of dislocation density. In addition to techniques used, a complete list of equipment needed is given. The company offers large grained polycrystalline material, doped and undoped, as well as single crystal. Monsanto Chemical Co., St. Louis, Mo.

Delay Lines 667

Modular delay lines for engineered prototype equipment, available on an "off-the-shelf" basis, makes possible overnight delivery of 500 ohm impedance delay lines in a wide range of delay characteristics. Each module is an encapsulated LC circuit which provides specific delay increments. Delay times range from 10 to 100 nanoseconds in 10-nanosecond increments and include phase correction for proper pulse response. With the aid of a graph developed by the company, you can determine the number of sections required in a prototype design if you know the delay to rise time ratio and the circuit impedance. (4 pp) Nytronics, Inc., Berkeley Hgts., N. J.

Bodine offers:

...the largest selection of small synchronous motors



More than 385 sizes and capacities... 1/2000 to 1/6 h.p. Two basic types of motor construction... RELUCTANCE in split phase—permanent split capacitor—and three-phase... with or without speed reduction. HYSTERESIS in permanent split capacitor—and three-phase. You receive ADE (After Delivery Economies) from all Bodine motors.

NEW—ask for 20-page Bulletin #1036 "Bodine Synchronous Motors."

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Bodine Electric Co., 2530 West Bradley Place, Chicago 18, Illinois

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SPEED SENSITIVE SWITCHES

An extensive line of speed sensitive switches, with variable mountings and drives are available to suit the needs of modern equipment. A single governor containing 1 to 6 speed switches can be furnished to trip at any given range.

Switch Container Dimensions

Available drives

GH . . . Built to S.A.E. tachometer specifications.
GS . . . For belt, chain, gear or coupling drives.
GA . . . Standard specification pad AND20005.
GW . . . General Motors standard for blower accessory drive.
GO . . . Direct mounting for tachometer take-off.
GY . . . Two bolt flange mounting.
GT . . . Provides 2 auxillary drive take-offs.

SYNCHRO-START PRODUCTS, INC.
8151 NORTH RIDGEWAY AVENUE • SKOKIE, ILLINOIS

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Shaft Position Encoder 664

Eleven digit, photoelectric shaft position encoder converts angular shaft displacement into electrical signals for digital readout. This device accomplishes accurate angular and linear measurements; in one 360° rotation of the shaft it defines 2048 unique positions with a resolution of 10.55 minutes of arc per step. Absence of gears, brushes, tubes or transistors assures top reliability through use of a minimum of components. (4 pp) The Baldwin Piano Co., Little Rock, Ark.

Numerical Control 665

Presenting educational data on the growing machine tool-numerical control field, a booklet relates the history and development of metal removing machines and numerical control and defines the meaning of numerical control. Other subjects include: where numerical control is used, programming tapes, standardizing punched tapes and standardized programming. Tables show actual examples of cost savings in machining a part on a numerically controlled machine compared with manually operated machine. Booklet also presents automatic writing machine for punching and verifying 8-channel tapes for numerical control applications. (32 pp) Friden Inc., Rochester, N. Y.

Build-In Instruments 673

Designers guide information for including build-in instruments in end equipment is offered along with complete details on miniaturized panel-mounting dc and ac VTVM's and TRVM's. Fundamentals of range selection, scale plate selection, and principles and applications of phase sensitive voltmeters are among the topics covered. Trio Labs, Plainview, Long Island, N. Y.

Gyro Test Table 680

Four pages of data on a dynamic test table for inertial systems, gyros, accelerometers and pendulums. Dunn Engineering Corp., Cambridge, Mass.

Microwave Products 679

Forty two pages completely reviewing the Telerad microwave products covering coaxial transmission line equipment, antennas, waveguide, accessories, components and systems. Telerad, Div. of The Lionel Corp., Flemington, N. J.

Microwave Components 677

Six pages of general data and key specifications on MELABS, Palo Alto, Calif., microwave instrumentation and components. Included are new microwave sweep generators, laboratory receiver and some new miniature and ultra-miniature ferrite components.

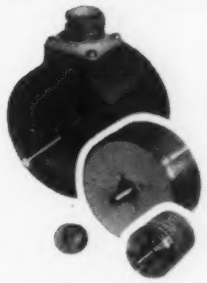
Ferrite Devices 675

Mechanical and electrical characteristics of more than 50 ferrite devices are detailed by Sylvania's Microwave Device Div. Frequencies, isolation and insertion loss, VSWR, power levels, dimensions and prices on devices that operate in the 1-Gc to 21-Gc frequency range, with isolation as high as 80 db and insertion loss as low as 0.2 db. Sylvania Electric Prods., Inc., Buffalo, N. Y.

How good is OPTISYN®?

Here are some of the facts... you be the judge.

OPTISYN is an incremental shaft-angle transducer, capable of generating 2048 (or more) precisely-placed counting pulses per input shaft revolution in tiny Size 11 (1.1 inch case diam.); over 4000 counts per turn in larger sizes. OPTISYN has no gears, no sliding contacts. It can produce 100,000 reliable pulse counts per second, at shaft speeds up to 30,000 rpm! Counters have trouble keeping up with OPTISYN.



Sizes 11, 23, and 27 in growing OPTISYN line.

WHAT'S THE SECRET? OPTISYN is based on a unique OPTICAL GEARING principle that results in 4-times increase in resolution, dependable wide-aperture optics, and valuable error-averaging. Accuracy and reliability are the result. OPTISYN is standard equipment on Titan missile, offers 6 years mean-time-to-failure, and ruggedness to meet MIL-E-5272C.

VARIATIONS? Special designs, including pancake shapes, are in production for inertial accelerometers, gyro gimbals, pedestal mounts, industrial uses, etc. Output electronics also available to match high-performance OPTISYN into your digital system. Want more information?

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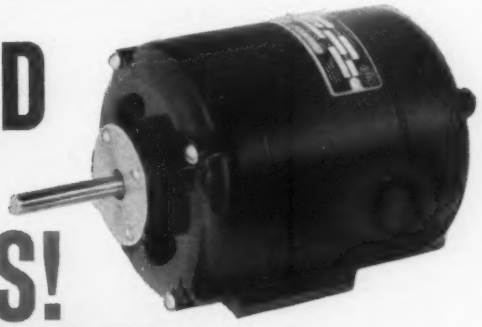

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1/12 TO 1/4 H.P.

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So fine a motor, all mating surfaces are **machined**—not die-cut—for closest possible tolerance! Assures uniformity of air gap for minimum cogging, uniform output. For communications, hospital, dental, metering and hydraulic pump equipment, computors and other applications.

Write today for complete details!

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Shunt or Compound—1/12
Intermittent:
Series—1/4 @ 10,000 RPM
Shunt or Compound—1/6
SPEED:
No Load: Series—15,000 RPM
Shunt or Compound—12,000 RPM
Full Load: Series—3,000 to 10,000 RPM
Shunt or Compound—1,000 to 10,000 RPM
VOLTAGES:
Series—6 to 250V AC/DC
Shunt or Compound—6 to 230V DC

Divisions: Electric Motor Corp. Cyclohm Motor Corp. Loyd Scruggs Co. Racine Electric Products

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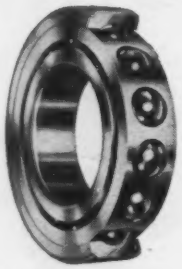
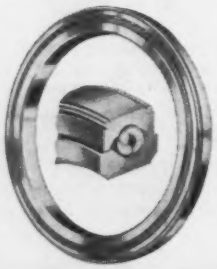
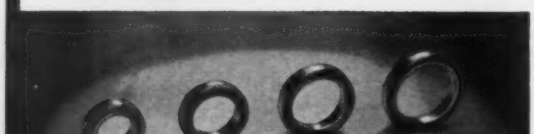


HDR SERIES High precision radial ball bearings with maximum ball complements in deep groove races uninterrupted by filling slots or counterbore — extra high capacity — made in four metric series, in ABEC 3 and ABEC 5 precision grades.



T SERIES Thin-section, high precision radial ball bearings. Type TCR with maximum ball complement and retainer — Type TCF with full race ball complement — Type TWF with unique integral shield.



MIDGET T's Small, thin-section radial ball bearings with maximum ball complements and one-piece retainers — high concentration of load capacity in minimal space results in tremendous space savings.

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Split Ballbearings have many advantages over conventional ballbearings because of our exclusive and patented method of construction. The result is a new kind of precision ballbearing with the following superior performance abilities:

MORE LOAD CAPACITY — up to 56% more radial capacity than conventional Conrad-type bearings while maintaining full thrust capacity in either direction. **LONGER SERVICE LIFE** — up to 280% more life than conventional Conrad-type bearings, without sacrificing load capacity. **ONE-PIECE RETAINER** — strong, light, precision made. **SPACE SAVING** — more capacity in a given bearing envelope means smaller bearings may be used. **LOW TORQUE** — maximum ball complements and precision one-piece retainers provide better load distribution within the bearing, effectively reduce starting torque, and minimize running torque. **GREATER RIGIDITY, LESS DEFLECTION, INCREASED RESISTANCE TO SHOCK LOADS** — all these advantages derive from using maximum ball complements in deep groove bearings without filling notches or counterbored rings . . . possible only with Split's patented construction method. **INTEGRAL SHIELDS** — truly integral shields in thin-section bearings . . . no ring distortion. **SPECIAL DESIGNS** — Split Ballbearing's method of construction brings new solutions to difficult bearing problems. As a result, many of these incorporate special bearing designs. You are invited to consult with our Special Bearing Engineering Group for new approaches to your particularly difficult bearing problems.

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SBB DIVISION OF MPB INCORPORATED

LEBANON, NEW HAMPSHIRE

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CATALOGS

Semiconductor Transducer 655

8-page brochure contains design and performance data. For either analog or digital systems, silicon semiconductor strain gage tranducers are responsive to both static and high frequency dynamic pressures, and are fully compatible with existing military air, ground and underwater telemetry and industrial systems. Producing a high output dc signal eliminates the problems associated with low signal-to-noise ratio and the necessity of an external amplifier. Fairchild Controls Corp., Hicksville, Long Island, N. Y.

Power Supplies 659

Long form catalog covers complete line of regulated power supplies. Latest developments in regulated transistorized power supplies, complete specs and latest engineering designs are included. (44 pp) Harrison Labs., Inc., Berkeley Hghts., N. J.

Ceramic Capacitors 651

In a 16-page booklet ceramic capacitors are indexed in terms of their high-reliability specs, military part numbers and range of temperature characteristics. Units are available in six case sizes in each temperature characteristic, in dipped plastic or glass-coated form and in plastic molded cases. Special section covers tubular plastic molded case capacitors designed for insertion by machine. Component Sales, Gulton Industries, Inc., Metuchen, N. J.

Adjustment Potentiometers 661

Designed for quick reference, brochure summarizes key information on 20 basic pot models including resistances, terminal types, power ratings, operating temperatures, dimensions and prices. It includes information on 6 recently released models ranging from a commercial unit selling at under $1.00 to a high power model rated at 15 watts. Cutaway drawings of 4 models illustrate the internal construction and point out the outstanding design features. (4 pp) Bournes, Inc., Trimpot Div., Riverside, Calif.

Directional Couplers 676

Four pages detail a line of coaxial line directional couplers in both quick-clamp and bolted-flange types. Particular features are high directivity and adjustable r-f output. Because source impedance is matched to the characteristic impedance of connecting cable, the coupling coefficient is unaffected by cable length. Based on the angular orientation of the coupler, either incident or the reflected wave may be sampled. Dielectric Prods. Engr. Co., Inc., Raymond, Maine.

Differential Transformers 672

Described as an invaluable aid to design, bulletin contains the theory and application of Atcotran linear variable differential transformers for measuring linear displacements. Military specifications and special differential transformer characteristics are tabulated. (12 pp) Automatic Timing & Controls, Inc., King of Prussia, Penna.

Microwave Components 956

Over 200 standard precision microwave components, covering a range from 1.70 to 40 GC, including ferrite devices, precision low-power terminations, directional couplers, standard gain horns and detector mounts, are calibrated on instruments traceable to the NBS. Components developed for specific applications are available in their original design or modified to meet special requirements. (8 pp) Microwave Components & Systems Corp., Monrovia, Calif.

Display System 957

Designed for monitoring readout in analog computing as well as general laboratory instrumentation, multi-channel calibrated display system measures and displays complex phenomena with accuracies comparable to conventional X-Y chart recorders but at speeds typical of large screen oscilloscopes. Booklet on this unit also describes principle of operation of "Electronic Graph Paper." (12 pp) Philbrick Researches, Inc., Boston, Mass.

Modular Mass Memory 953

Catalog entitled "Modular Mass Memory" describes disc files with capacities from 30,000,000 to 720,000,000 bits. Files are available with from one to 24 discs. Details of the digitally-addressed, mechanical-hydraulic head positioner, the magnetic heads and head bar assembly, the magnetic discs and integrated electronic packages are included. Typical serial and parallel operations are covered. (12 pp) Bryant Computer Prods. Div., Ex-Cell-O Corp., Walled Lake, Mich.

Resistance Standards 683

Techniques for establishing resistance ratio accuracy to one part in ten million are described. Included are discussions of ultra precise ratio measurements, resistor error, theoretical ratio and ratio error and the establishment of a uniquely accurate and stable primary reference of ratio. Test circuitry drawings illustrate all phases of discussions. (4 pp) Julie Research Labs., Inc., N.Y.C., N. Y

Servo Motor Package 678

Four pages describe a servo motor package developed for use in missile and aircraft control systems that incorporates the hydraulic motor, servo valve and internal relief valves in one housing. Vickers claims that this is a unique departure from a standard servo motor with manifolded flow control servo valve and internal relief valves. Design details and operating characteristics are included. Vickers, Inc., Div. of Sperry Rand Corp., Detroit, Mich.

Electrical Contacts 654

"Basic Guide to Electrical Contacts" includes charts covering applications, technical data for the various contact alloys and specifications of the most commonly employed stock contacts. Other sections discuss points to be considered in the design, specification and purchase of rivet contacts, laminated contacts, springs and blades and complete assemblies. (8 pp) Tricon Mfg. Co., Chicago, Ill.

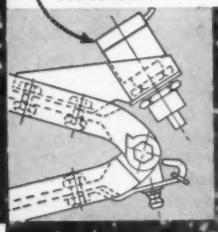
HAYDON Switch

SEALED Switches designed for environmental challenge!

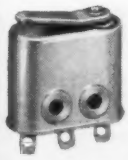
MINIATURE SPDT LANDING GEAR SWITCH...

Exposed to ice, water and mud. Corrosion resistant throughout, potted leads, sealed plunger. Meets icing operation requirements.

Series 61574



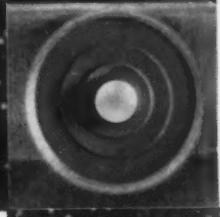
Haydon hermetically sealed switches qualified to MIL-E-5272 and MIL-S-6743.



Series 61392

METAL TO METAL, GLASS TO METAL SEAL...

Low temperature—high temperature from −300°F. to +500° F. and beyond. Wobble diaphragm withstands 200 PSI without changing characteristics or actuating switch.



BONDED SILASTIC ACTUATOR SEAL...

Subjected to 8 weeks and million cycle test immersed in JP-4 fuel. Tested for 100,000 cycles at 28 vDC, 3 amps inductive at 80,000 feet.

STANDARD HERMETICALLY SEALED SWITCH...

Low operating force version is ideally suited to critical applications requiring extreme accuracy such as timing, pressure and temperature sensing devices.

Series 6146

NOW... Write for New Haydon Switch General Catalog Showing Miniature, Subminiature, Hermetically Sealed, Pressure Switches and Custom Designed Switch Assemblies.

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For Your 3-Ring Binder
NEW DATA SHEETS

Most of these data sheets contain complete specs, mounting configurations and other details associated with the application of the products described.

Airborne DC Amplifier 938

Small (4.75 cubic inches), solid state, direct-coupled differential input, dc amplifier designed for extremely rugged operational environments is described. Absence of any form of chopper gives extended frequency response, freedom from hash and rapid recovery from overloads. DC gain is 200 to 1000, 10.75%. Microdot Inc., S. Pasadena, Calif.

Snap-Action Switch 904

Important features of new low cost precision snap action switch are mechanical and electrical reliability, easy and fast installation, versatility with manual and mechanical operation and electrical safety. Made of durable white nylon, the switch snaps into panels without the use of tools. It is ideal for use on refrigerators, vending machines and other such applications. It has an electrical rating of 10 amps up to 250 vac and ¼ hp 125 vac. Micro Switch, Freeport, Ill.

Capacitors 905

Silicone rubber molded wafer capacitor, an improved version of the standard wafer, is especially suited to applications involving shock, vibration and temperature and altitude extremes. Data sheet also describes other capacitors made with interleaving copper foil, special dielectric material and a low-loss thermoplastic bonding resin. Units are stacked under controlled high temperatures and pressures to form a durable, moisture-resistant, monolithic block with indefinite shelf life. AMP Inc., Elizabethtown, Pa.

Hi-Temp. Boards 939

Using glass — silicone lamimeter and copper conductive patterns, have undergone functional testing under actual operating temperatures of 150° to 250° continuously. Named Cu-Sil, the boards are being manufactured with plated-through holes and finishes of gold or high temperature solder; also available as multilayered and built-in shielding. Conductorlab, Inc., Groton, Mass.

Permanent Magnets 935

Severe temperatures and other environmental conditions have made the use of permanent magnets impractical for many applications. Properties of a new magnet, Alnico VIII coupled with excellent temperature stability allows practical design in those areas, according to manufacturer. The company reports that Alnico VIII has over twice as much resistance to demagnetization as Alnico V, and it is substantially higher in both coercive force and maximum energy product than Alnico VI or VII. Company also claims the best magnetic stability of any commercially available permanent magnet material. Crucible Steel Co. of America, Pittsburgh, Pa.

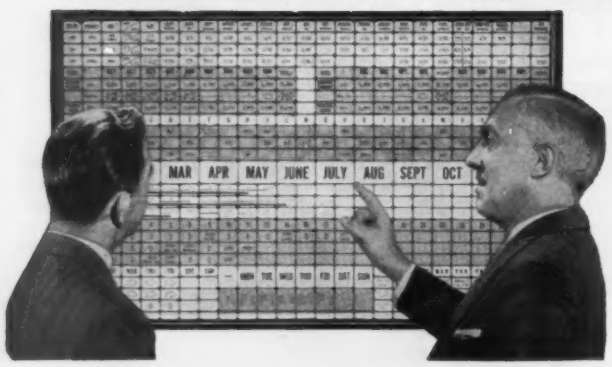
Power Supplies 907

feature 65°C base mounting temperature and operation at full ratings with heatsink at up to 35°C ambient temperature. The modular transistor—regulated units are ideal for laboratory and prototype work and are low priced. Power Sources, Inc., Burlington, Mass.

Extension Springs 948

Provide constant force at all deflections. Series of data sheets have step-by-step procedure for designing these elastic members along with fourteen easy-to-use design tables. Descriptions of load-deflection and size-load-life characteristics, mounting considerations and application limitations are included. Hunter Spring Co., Div. Amer. Machine & Metals, Inc., Lansdale, Pa.

You Get Things Done Better By Seeing What's Happening



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Silicon Rectifiers 943

Miniature hermetically sealed silicon rectifiers specifically developed to replace the larger top hat types are in a cylindrical package 0.250" long by 0.225" in dia. and are mounted by their axial wire leads. Although the units are approximately one half the size of the top hat, no heat sink is required, making them ideally suited to printed wiring board applications in voltage ranges from 50 to 600 PIV. Slater Electric, Inc., Glen Cove, N. Y.

Constant Voltage Supply 944

An extremely stable, space saving unit to replace dry cells and manual standardization circuitry in potentiometer and Wheatstone Bridge type instruments, a constant voltage supply developed by The Thermo Electric Co., Inc., Saddle Brook, N. J., also can provide 1.5 volts dc at rated load of 1.4 ma in any other application requiring high stability and dependability.

Electric Integrator 946

For precise integrating of flows that can be represented by a signal in the 0-25 volt range, GPE Controls, Inc., Chicago, Ill., offers an electric integrator, Model R 790. Integration is continuous and accurate to within ½ of 1% with flow turndowns of as much as 10 to 1. Direct 6-digit readout eliminates chart planimetering. DC motor with speed proportional to the applied voltages drives the precision gear train and counter; the motor has jeweled bearings and precious metal commutator. Instrument is insensitive to temperature changes between −30° and +130°F.

High Pressure Transducer 945

Low cost transducer provides a potentiometric output with very wide pressure range coverage. Designated Series HPT-10, this reliable, precision mechanism is capable of withstanding critical environments including operating temperatures of −55°C to +100°C and measurement of corrosive and non-corrosive media. Full scale range is 0-100 psia or psig to 0-10,000 psia or psig with a static accuracy band of ±1.5% or better available on most pressure ranges. Resolution is 0.22 to 0.33%. DeJur-Amsco Corp., Instr. Div. Long Island City, N. Y.

High Current Switches 947

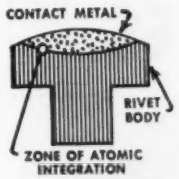
Making and breaking 25 amps at 125 or 250 volts ac, in single-pole double-throw circuits, Unimax 2HG series snap-acting switches meets performance requirements where high currenthandling capacity is of primary importance. Available in basic style with pin actuator, and with overtravel-plunger, leaf, leaf-roller, lever and roller-lever actuators, it is furnished in three standard base styles: with solder-lug terminals; with step base and screw terminals; and with front-facing screw terminals. Unimax Switch, Wallingford, Conn.

Temperature Control 934

Specs on two control units are given. One is a new high temperature (0 to 1000°F) indicating control. The other is a low cost compact short range indicating temperature control. Applications, construction details and control ranges are fully described. United Electric Controls, Watertown, Mass.

Gibson Atomiclad* Electrical Contact Rivets now available in economical Gibson Assemblies

ATOMICLAD RIVETS ARE LOWER COST BECAUSE IT COSTS LESS TO MAKE THEM



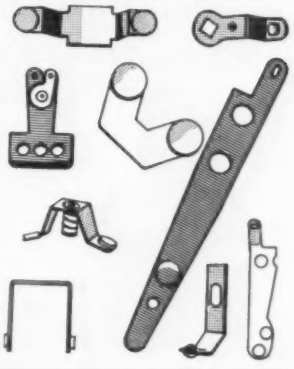
Patents Pending

And they're BETTER because their bond of dispersed atoms of the precious contact metal and the base metal of the body is electrically and mechanically superior to other bonding methods. Cost is further reduced by limiting use of precious metal to electrical requirements of the contact.

Atomiclad Rivets are made in all standard forms and of copper, steel or other base metal with contact face of precious or semi-precious metals.

Many sizes and types are stocked in quantity. Write for Standard Stock List #2007, and for Technical Information Bulletin 400.

ECONOMICAL GIBSON CONTACT ASSEMBLIES



Gibson contact support manufacturing facilities include every phase—forming, riveting, heat-treatment and electroplating and comprises use of any specified metal.

When you specify Gibson Contact Assemblies, you get the benefit of years of engineering know-how in providing the best possible electrical union between contact and support member. Since all assemblies are Gibson-inspected, the customer suffers no loss through assembly rejects.

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*ATOMICLAD—Trademark Gibson Electric Company

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Quality built, hermetically sealed capacitors with a voltage range of 2,000 to 10,000 volts; from 1 Mfd. to 10 Mfd. Advanced production facilities, more expert engineering combine to make possible these quality capacitors from the capacitor people who consistently deliver more performance, more value and more satisfaction.

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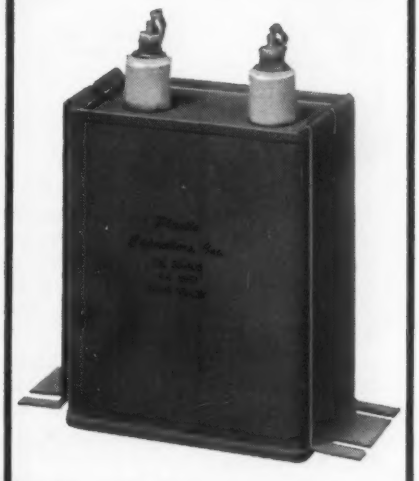

Plastic Capacitors, INC.

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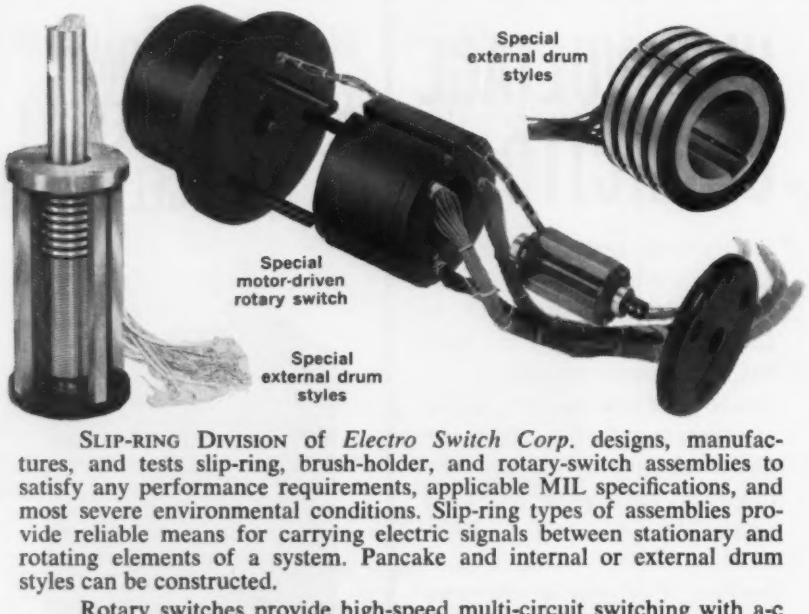
STANDARD and SPECIAL manual and motor-driven ROTARY SWITCHES

ELECTRO SWITCH CORP. designs, manufactures, and tests standard and special rotary switches for the most complex electric and electronic circuits. The standard switch types range from 2 to 16 positions and from 0.5 to 200 amperes.

Special rotary switches are assembled from standard parts and, if necessary, to meet MIL specifications.

Please write for latest catalog of manually operated rotary switches or for the catalog of ammeter, voltmeter, and other instrument switches.



SLIP-RING DIVISION of *Electro Switch Corp.* designs, manufactures, and tests slip-ring, brush-holder, and rotary-switch assemblies to satisfy any performance requirements, applicable MIL specifications, and most severe environmental conditions. Slip-ring types of assemblies provide reliable means for carrying electric signals between stationary and rotating elements of a system. Pancake and internal or external drum styles can be constructed.

Rotary switches provide high-speed multi-circuit switching with a-c or d-c motor drives. High-precision commutator segments range from subminiature dry-circuit sizes to heavy-duty power-handling sizes.

Please write for Bulletin 60-01 describing slip-ring and motor-driven rotary switches.

ESCO of WEYMOUTH
ELECTRO SWITCH CORP.
Weymouth (Boston 88), Massachusetts

CIRCLE NO. 66 ON INQUIRY CARD

DATA SHEETS

Torque Indicator, 910

an automatic null-balance unit, is calibrated specifically for use with company's standard torque pickups. Indicator features a large pointer and high-visibility dial. Only one control is included — a zero set knob for adjusting the pointer before each run when torque is not applied to the pickup. Indicator scale is used as a percent of capacity and average torques are indicated even with pulsations of up to ±10% of full-scale. Baldwin-Lima-Hamilton Corp., Electronics & Instrumentation Div., Waltham, Mass.

Two Pin Connector 912

meets applicable paragraphs of MIL-C-5015 and MIL-C-8384, data sheet lists all physical and electrical characteristics. Lionel Electronic Labs., Brooklyn, N. Y.

Electronic Interval Timers 911

eliminate motors, clutches and solenoids. Eight transistorized models cover timing intervals from 0.5 sec to 5.0 min. Timing interval is adjustable by a control knob or slotted shaft with locknut. Standard models operate from 115 v ac line and timers for operation on dc (as low as 28 v) can be supplied. Electro-Seal Corp., Des Plaines, Ill.

Laboratory Power Center 914

is a self-contained source of three kinds of precisely regulated power: 60 cps and 400 cps ac at 5 kw, and 24-28 vdc at 3 kw requires only a connection to an unregulated 60 cps, 3 phase- source. It has a wide range of uses where exceptional stability and complete freedom from line transients are required. Electric Specialty Co., Stamford, Conn.

Miniature Rheostat 915

rating 12½ watts, is available with tapered windings consisting of 2 or more sections each using a successively smaller diameter wire. Advantages of tapered windings are more linear control of certain loads; higher maximum resistance for a given current rating; production of specific resistance versus rotation curves. Only ⅞" in dia. and extending only 11/16" behind the mounting panel, this Model E rheostat has ceramic hub, independent contact arm pressure, vitreous enamel coating and metal graphite contact. Made to order to customer specs. Ohmite Mfg. Co., Skokie, Ill.

Piezo-Electric Ceramic Elements 913

fabricated from lead titanate lead zirconate ceramic, are available in discs, blocks and cylinders. The basic ceramic has been modified in each case in order to best suit the intended use: type D operates under high ac fields and has ultrasonic power applications; type E has high electromechanical activity and is best suited for ultrasonic receiver applications; type F features the time and temperature stability necessary for electric filter applications. General Instrument Corp., Newark, N. J.

Pressure Transducer 902

gives fast response in measuring dynamic pressures encountered in the testing of rocket, jet or turbine engines, hydraulic systems, and high speed chemical reactions. Unit operates over the pressure ranges from 0-300 to 0-10,000 psig. Extremely small fluid pressure cavity, constructed of stainless steel, to permit measurement of peroxides, liquid oxygen, alkalies, and corrosive acids, insures the fast action. Stainless steel diaphragm and seal provide positive protection of the electrical measuring element from the media in the pressure cavity. Linearity deviation is less than 0.25% of full scale from a straight line function determined by least squares method. Taber Instrument Corp., N. Tonawanda, N. Y.

Dial Light Socket 916

for data computers, processing equipment, switchboards and automation applications is printed circuit assembly providing quick, easy and safe wiring with a minimum of handling and connection points. Common side is prewired, leaving only one lead per socket for hand wiring. Either vertical or horizontal reading is possible. Standard socket strips contain twelve 3/8" dia bayonet base lamp sockets spaced on 5/8" centers. All circuits are solder dip coated. Allegri-Tech, Inc., Nutley, N. J.

Circuit Card Enclosure 917

recent development in printed packaging techniques can be easily assembled and mounted in front-loading rack or top-loading drawer positions. It accepts and holds up to 24 cards in perfect card-connector alignment. Designed for use with standard-off-the-shelf connectors, unit accommodates different card lengths by using any of three available depths. Epsco-Components, Cambridge, Mass.

Synchronous Motor 918

for special applications where power is required at constant angular rotation with no "cogging" provides low speed operation at high frequencies. Variations in angular displacement of the armature are held within ±0.1°, nominal load variations. Capable of operating from a vacuum tube amplifier on frequencies up to 3600 cps, unit is provided with an integral (1750 rpm @ 60 cycle) start motor. The (60-pole rotor) characteristics of the motor determine the shaft speed without gearing. This motor can be operated single phase in the plate circuit of a single-ended amplifier, or as a two phase motor when driven by a push-pull amplifier providing up to 1/100 hp. Motor current is approximately 75 milliamps per phase. Westrex Co., Div. Litton Systems, Inc., New York,

High Beta Transistor 919

in metal JEDEC to —5 enclosure which provides good electrostatic shielding is three terminal device containing a matched pair of hermetically sealed NPN diffused mesa silicon transistors in a composite configuration so as to obtain extremely high current gain while maintaining high stability. Current gain (Beta, Hfe): exceeds 5000; current range: from 1 ma to 500 ma; dissipation: 1 watt at 25C case temperature. Solid State Electronics, Sepulveda, Calif.

When it comes to linear and non-linear single-turn *precision* potentiometers, consult Raytron *first!* They are the culmination of an unusual combination of extensive research, experienced engineering and unexcelled production and testing facilities.

New winding techniques and special machinery developed by Raytron assure both conformity and uniformity to meet *your* specifications, whether standard or special.

Write for the new Raytron Catalog.

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A SUBSIDIARY OF INSTRUMENTS FOR INDUSTRY, INC.

CIRCLE NO. 67 ON INQUIRY CARD

SHOWN ACTUAL SIZE

SIZE 5 COMPONENTS

FOR SERVO SYSTEM MINIATURIZATION

A complete family of Size 5 components for every servo system function is now available from Kearfott. Stainless steel housings, shafts and bearings protect the units against environmental extremes and contribute to stability under shock, vibration, and temperature fluctuations. • Standard 26-v, 400-cps excitation. • Operating temperature range −55° to +125°C.

CHARACTERISTICS

SYNCHROS

	VOLTAGE (400 cps)	T.R.	NULL (mv)	ERROR (min)
Transmitter				
CJO 0565 100	26	.454	34	10
Control Transformer				
Low Z-CJO 0555 100	11.8	1.765	34	10
High Z-CJO 0552 900	11.8	1.765	34	10
Differential				
CJO 0595 100	11.8	1.154	34	10
Resolver				
Low Z-CJO 0585 100	26	1.0	34	10
High Z-CJO 0589 100	26	1.0	34	10

SERVO MOTORS

	J126-06	J126-02
No-Load Speed	9800 rpm	9800 rpm
Stall Torque	0.10 in. oz	0.10 in. oz
Rotor Moment of Inertia	0.175 gm cm²	0.175 gm cm²
Voltage $\phi 1/\phi 2$ (400 cps)	26/36-CT	26/26
Power Input/Phase	1.7 w	1.7 w

SYNCHRONOUS MOTOR

	CJO 0172 200
Pull-In Torque	0.06 in. oz
Pull-Out Torque	0.10 in. oz
Pull-Out Power	4 w

MOTOR GENERATORS

MOTOR	CJ40812001	CJ00812650	CJ00813200
Voltage $\phi 1/\phi 2$ (400 cps)	26/36-CT	26/36-CT	26/26
Power /ϕ	1.5 w	1.5 w	1.5 w
No-Load Speed	8000 rpm	8000 rpm	8000 rpm
Stall Torque	0.10 in. oz	0.10 in. oz	0.10 in. oz
GENERATOR			
Voltage (400 cps)	26 v	26 v	26 v
Volts/1000 RPM	0.1 v	0.1 v	0.5 v
Null	1.3 mv	10 mv	6.7 mv

Size 5 gearheads range in reduction ratios from 20:1 to 1019:1 for servomotors and motor tachometers above. In addition to Size 5 clutches, brakes, and brake-clutches, Size 6 are available.

Write for complete data

KEARFOTT DIVISION
GENERAL PRECISION, INC.

Little Falls, New Jersey

CIRCLE NO. 68 ON INQUIRY CARD

BOOK REVIEWS

(Continued from page 4)

Selected Semiconductor Circuits Handbook

Edited by: Seymour Schwartz
Price: $12.00
John Wiley & Sons, Inc., 1960
440 Park Ave. So., New York 16, N.Y.

Although new circuit and new semiconductor techniques appear at a furious rate, this book has a real and lasting value. It covers, in a very useful way, many proven and stable solutions to design problems. The engineer's philosophy often makes him use the configurations he is most familiar with and this book is ideal for expanding and developing a good, proven, "bag of tricks". It is very useful for the practicing transistor circuit designer, but I do not recommend it as a first exposure to transistor circuits because it requires a rather good idea of how transistors work.

In each chapter a short section on theory is followed by a number of proven circuits with rather quick comments on their features. Actually many engineers will be familiar with this type of approach since it is found in the various Military Departments' preferred circuits handbooks. Mr. Schwartz presents chapters on direct-coupled amplifiers, oscillators, switching circuits, logic circuits, ac to dc power supplies, small-signal non-linear transistor circuits.

Martin Glasberg, Contributing Editor

Beyond The Planet Earth

Konstantin Tsiolkovsky
Price: $3.75
Pergamon Press
122 East 55th St., New York 22, N.Y.

The early science fiction stories of Jules Verne and H. G. Wells are now classics which form part of almost every scientist's library. We are still amazed at the accuracy of some of the predictions made by these two authors.

Less attention has however been paid to similar works by authors from other countries. Particularly is this so when we consider the work of Tsiolkovsky. This book "Beyond the Planet Earth", although written in a very cursive manner, is, one could almost say, fantastic in the insight which is demonstrated by the author of the problems encountered in space travel. The astonishment which this reviewer felt can best be realized when it is known that this book was originally written in Russia at

the turn of the century, long before we even thought of heavier-than-air craft, and yet Tsiolkovsky was able, with the information then available, to prognosticate and predict the problems and the solutions to the problems which will be inherent in space travel.

This reviewer believes that this small book will provide not just a casual reading for all engineers interested in space travel but will certainly provide them, with the incentive to apply all of our existing knowledge to solutions of their problems rather than adopting, as is sometimes the case, the attitude that "this problem can be solved if we have more information." Obviously Tsiolkovsky was not bothered with this situation and blithely went ahead solving problems on the basis of information already existing.

Pergamon Press are to be congratulated on this translation. In some places the wording is a bit stilted but this is to be expected in view of the great difficulty in transliterating Russian into idiomatic English, but generally the translator, Kenneth Syers, has done a good job. I highly recommend this book to all engineers.

Metals Handbook

American Society for Metals
Novelty, Ohio
1300 pages, $30.00

This 8th edition of a Handbook which is devoted exclusively to the selection and properties of metals has been greatly expanded over previous editions. Volume not only provides a large single storehouse of reliable information about metals but also emphasizes the factors of economy and fabricating in metals selection. More than 1300 metal specialists are named as contributors. Section on carbon and low-alloy steels consists of 26 major articles covering all commercial steel product forms, an appendix on the design of steel springs, and special articles dealing specifically with selection for maximum yield strength at minimum cost, hardenability, fatigue resistance, notch toughness, wear resistance, and resistance to corrosion. Compared to the previous edition, the new volume offers nearly six times as much numerical information in the form of charts, graphs, and tables. Many articles dealing with metal selection for specific engineering properties are entirely new. Also, more pages are assigned to magnetic, electrical, and other special-purpose metals, precious metals, and – a subject of rapidly expanding interest to designers – the properties of pure metals.

LARGEST NUMERICAL DISPLAY AVAILABLE

WITH KEARFOTT'S DME COUNTER-INDICATOR

With numerals 5/16" in height, this Kearfott unit has a larger, more easily read numerical display than any other DME indicator. This size factor contributes greatly to speed and accuracy in reading, and it provides an added margin of insurance against navigational error.

The Kearfott Single DME Counter-Indicator shows distance (in units, tens, and hundreds of nautical miles) from the aircraft to a navigational beacon. A mask with rectangular apertures allows only the significant calibrations to be seen; and when no signal is impressed, a red flag extends across the apertures to prevent reading. The unit is hermetically sealed and is filled with dry inert gas for trouble-free dependability and maximum service life.

In addition to the Single DME Counter-Indicator (T8510-11N) shown above, a Dual DME Counter-Indicator (T8511-11N) is available which indicates aircraft distance from each of two navigational beacons. The units meet environmental requirements and other applicable portions of RTCA Paper 100-54/DO-60.

SPECIFICATIONS

			T8510-11N (SINGLE)	T8511-11N (DUAL)
ACCURACY		Units Drum	±.05 mi	±.05 mi
		Tens Drum	±1/32 in.	±1/64 in.
		Hundreds Drum	±1/32 in.	±1/64 in.
SPEED		Either Direction	15 mi/sec	15 mi/sec
POWER		Rotor Voltage	26 ±2v ac, 400 ±10 cps	26 ±2v ac, 400 ±2 cps, 1 ph
		Flag Voltage	28 ±2v dc, 0.3 amp max	28 ±2v ac
WEIGHT			1¾ lbs	3 lbs

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KEARFOTT DIVISION
GENERAL PRECISION, INC.

Little Falls, New Jersey

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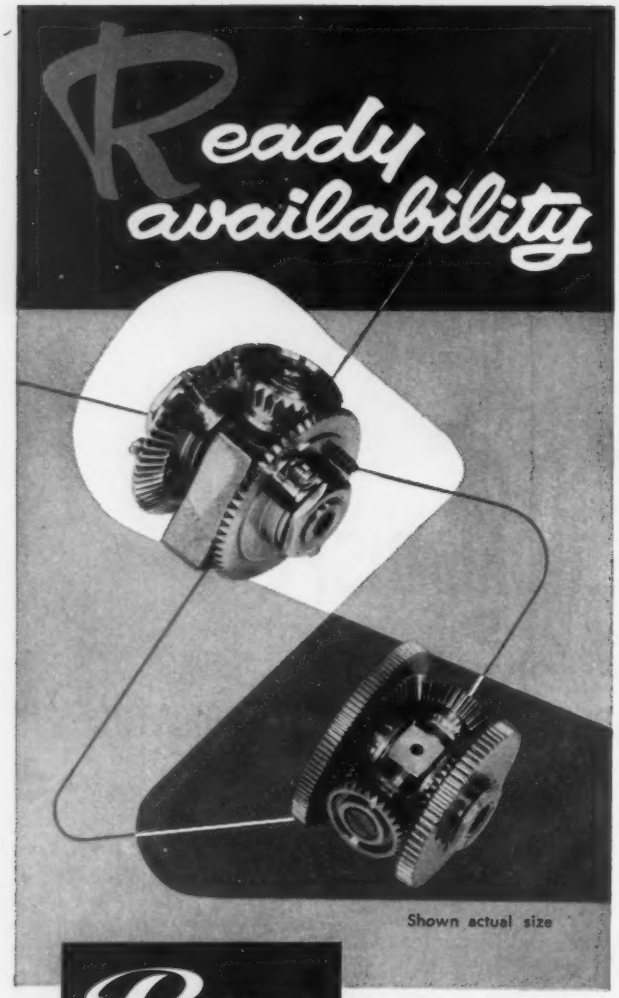

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The ultimate in precision differentials for computer applications. Available from stock in single and double pinion models. Hollow shaft design and readily interchangeable end-gears simplify field installation and maintenance.

Specifications: *Speed:* Up to 10,000 r.p.m. *Torque:* To 32 in-oz. *Starting Torque:* 0.01 in-oz. *Backlash:* As low as 1.5 minutes of arc. *End gearing:* Completely interchangeable.

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Computing Differentials are only one product in the COMPLETE Reeves Series of high-precision Servo-Mechanical Parts, recognized by engineers as an industry standard for highest accuracy and reliability.

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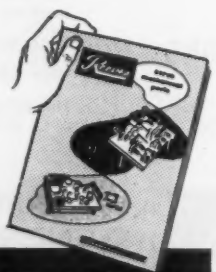

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REEVES INSTRUMENT CORPORATION
A Subsidiary of Dynamics Corporation of America
Roosevelt Field, Garden City, New York

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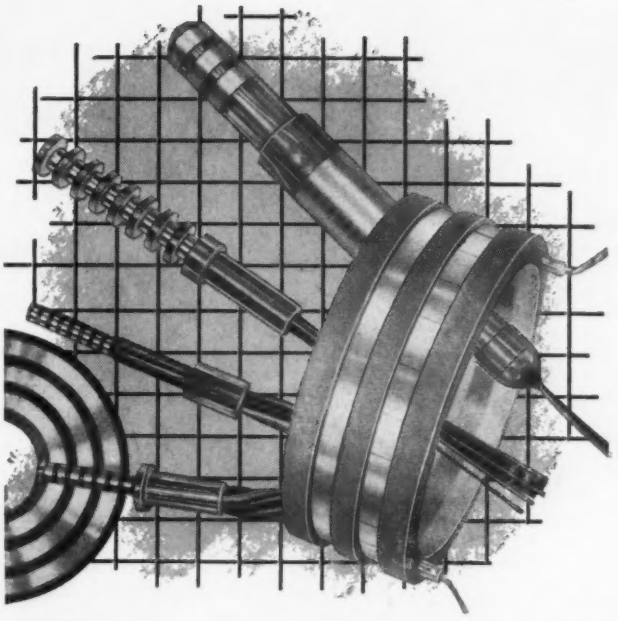

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MEMCOR designs and produces all types to your exact performance needs

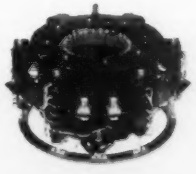
- **RF types to 600 mc, with a VSWR of less than 1.5**
- **All configurations**
- **Materials and properties to specifications**

MEMCOR designs and produces all kinds of precision slip ring components and assemblies from microminiature, "pencil lead" sizes to large power handling types.

A few general configurations available include platter, coaxial and segmented designs, but any type or assembly can be engineered to suit application requirements.

MEMCOR produces these precision components and assemblies for radar equipment, fire control systems, synchros, attenuators, switching and coding devices, resolvers, computers, mechanically oscillating gear and for many other control and servo applications.

Complete capability will be explained upon request.



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50 frederick street • huntington, indiana
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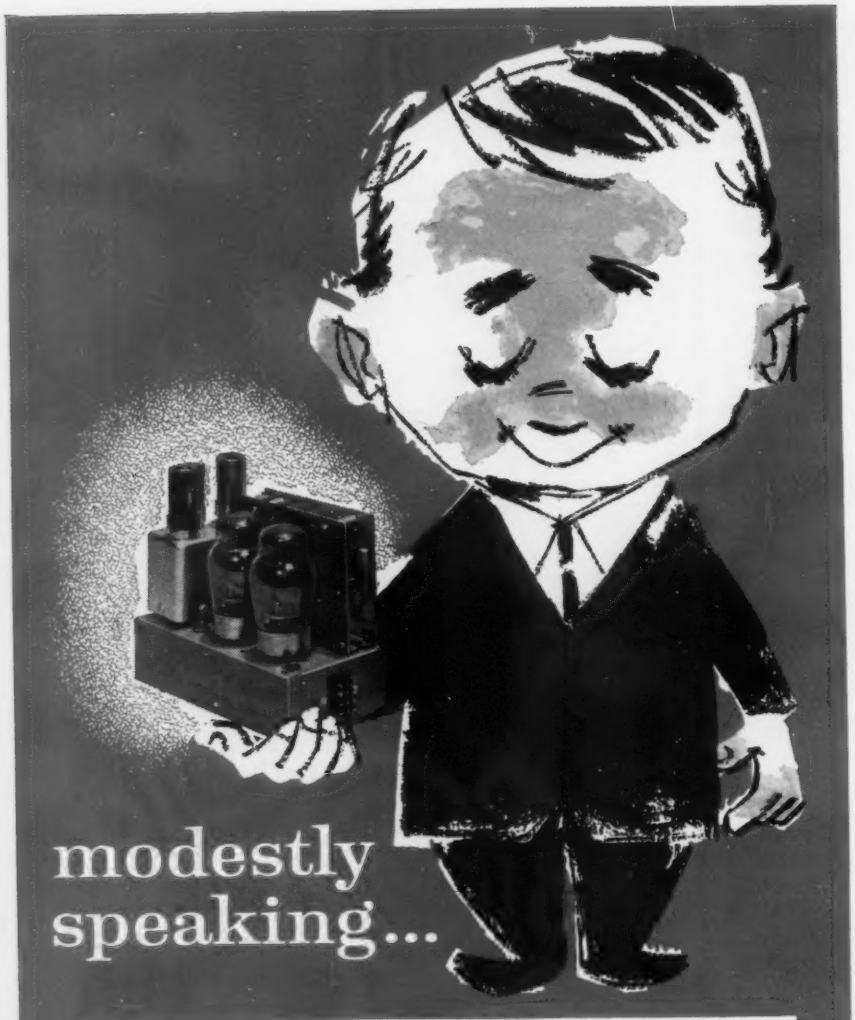

modestly speaking...

... We've really hit the jackpot with the new DIEHL Vacuum Tube Servo Amplifier. For response, linearity and power output, this new servo amplifier just can't be beat. Here are five reasons why:

- Continuous power output of 75 watts—drives DIEHL servomotors up to 25 watts 60 cycle, 15 watts 400 cycle.
- Minimum phase shift at carrier frequency.
- Plug-in input modules accept a wide range of AC and DC voltages.
- *Proven* vacuum tubes and printed circuitry assure maximum reliability.
- Separate amplifier and power supply chassis plug together.

Whatever the application, you'll find this newly perfected Vacuum Tube Servo Amplifier by DIEHL a welcome new standard of dependability and convenience. Why not get all the facts today? For additional information and/or applications assistance, contact: Diehl Manufacturing Company, Somerville, New Jersey. 4178

SPECIFICATIONS

Cat. No.	VA075-300
Output	75 Watts, Nominal
Gain	1000 volts volt in power amplifier with max. feedback. Feedback can be reduced with potentiometer provided, with resulting increase in gain
Input Imp.	500,000 ohms
Phase Shift	a) Less than 10° phase lag of envelope at one third carrier frequency b) Less than 2° at carrier frequency.
Noise	100 MV., Max., Input Shorted
Power Req.	Diehl VP3 100 high voltage power supply, or equivalent.

Diehl†

†A Trademark of THE DIEHL MANUFACTURING COMPANY

DIEHL MANUFACTURING COMPANY

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Somerville, New Jersey

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KEY's molded resistors maintain precise stability ...regardless of environment!

Key's new Series of Epoxy Molded Precision Carbon and Metal Film Resistors maintain precise stability—even withstands thermal "plunge" shock test from −60° F to +365° F. —without change in characteristics.

Key's new molding process permits the utilization of a larger core size for a given wattage, yet retains environmental characteristics far exceeding any other resistor encapsulation method. Larger cores mean increased film surface area, resulting in improved reliability and stability through more efficient heat dissipation.

Typical of the characteristics of Key's coating material is its relative water absorption as shown:

MATERIAL	CONDITIONS: A.S.T.M. D570—40T
Key coating	.04%
Epoxy, molded, mineral filled	.10%
Diallyl Phthalate, glass filled	.12%
Diallyl Phthalate, mineral filled	.20%

Here is a resistor which gives predictable performance under all environmental conditions. *Precise* and *positive* in characteristics, the new Key Series of Epoxy Molded Precision Film Resistors are the finest obtainable for any application—aerospace, industrial or commercial—at economical cost.

METAL FILM				
KEY TYPE	WATTS 125°C	VOLTS	NOMINAL SIZE DIAMETER	LENGTH
KM2	0.1	100	.095	.235
KM5	0.125	200	.120	.300
KM60	0.125	250	.155	.413
KM65	0.250	300	.217	.568
KM70	0.50	350	.261	.706
KM75	1.0	500	.396	1.045

CARBON FILM				
KEY TYPE	WATTS 125°C	VOLTS	NOMINAL SIZE DIAMETER	LENGTH
E2	0.1	100	.110	.230
E5	0.125	200	.133	.295
E10	0.250	300	.133	.420
E20	0.50	500	.195	.600
E25	1.0	1000	.333	.955

KEY resistors

KEY RESISTOR CORPORATION

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NOW! 30 DAY DELIVERY

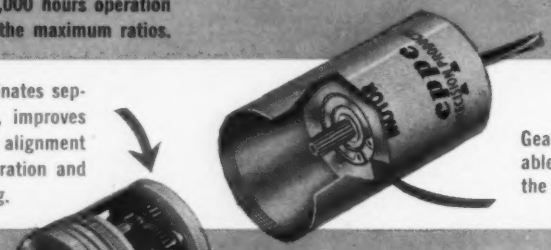
SIZE 8 & 10 INTEGRAL GEARHEAD MOTORS

3 Times Torque Load Capacity*

of comparable size 8 gearheads

*Will sustain 20 in-oz torque load for 1,000 hours operation and 100 in-oz momentary overload at the maximum ratios.

CPPC one-piece gearhead housing eliminates separate gear plates and fastening posts, improves and maintains accuracy through exact alignment of gear clusters, assures smoother operation and more expedient inspection and servicing.



Gearhead and motor are selectable, individual parts enclosed in the same common motor housing.

Clifton Precision, pioneers in postless gearhead construction, introduces the finest in gearhead design—cage-type, one-piece gearhead housing machined from a single block of metal. In these units, exact duplication of gear centers is accomplished through simultaneous boring of permanently integrated bearing plates (patent pending). Positive and permanent alignment of gear clusters composed of AGMA precision Classes II and III hardened-steel gears integral with shafts journaled at both ends in ABEC class 5 bearings, minimize deflection and backlash, maximize torque load capacity, insure smoother operation and continued reliability of performance beyond normal endurance life requirements. Cage-type construction facilitates inspection and lubrication while gearhead is mounted simply by removing motor.

CPPC motors will stand greater heat than ever before due to the use of new materials. See box at lower right.

Write for our free pamphlet which gives detailed specifications of our entire gearhead motor and motor-tachometer line, sizes 8, 10 and 11.

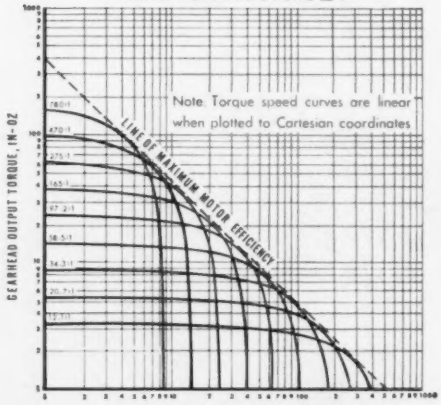
STANDARD TYPES

RATIOS Size 8	RATIOS Size 10	No. of Clusters	Dir. of Rotation
12.09	19.98	2 (3 pass)	reverse
20.63	32.19	3 (4 pass)	direct
34.26	58.28	3 (4 pass)	direct
58.44	93.89	4 (5 pass)	reverse
97.07	169.97	4 (5 pass)	reverse
165.58	273.84	5 (6 pass)	direct
275.02	495.74	5 (6 pass)	direct
469.15	798.70	6 (7 pass)	reverse
779.22	1445.92	6 (7 pass)	reverse

Notes: 1. Any ratio (±3%) is available within the limits of the ratio range at additional cost and may require longer delivery time. 2. Max. backlash = 30 minutes at 2 in-oz reverse gauge load in above units. Inquire if special tolerance is required.

PERFORMANCE CHARACTERISTICS

SIZE 8 INTEGRAL GEARHEAD MOTOR
SERVO MOTOR TYPE ALH-8-□-1


Note: Torque speed curves are linear when plotted to Cartesian coordinates
LINE OF MAXIMUM MOTOR EFFICIENCY
GEARHEAD OUTPUT TORQUE, IN-OZ
GEARHEAD OUTPUT SPEED-RPM

MOTORS

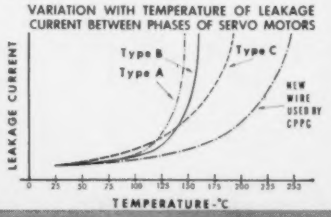
The following CPPC standard motors, electrical characteristics of which can be found in the current CPPC Rotary Components catalog, are offered with our gearheads:

SIZE 8		SIZE 10	
ACH-8-□-1	AMH-8-□-3	ACH-10-□-1	ALH-10-□-1
ACH-8-□-4	ALC-8-□-1	ACH-10-□-4	ALH-10-□-5
AMH-8-□-1	ALC-8-□-4		

CURRENT LEAKAGE

Superiority of insulation in CPPC motors is illustrated by actual comparative curves shown at the right.

VARIATION WITH TEMPERATURE OF LEAKAGE CURRENT BETWEEN PHASES OF SERVO MOTORS



CLIFTON PRECISION PRODUCTS CO., INC.
CLIFTON HEIGHTS, PENNSYLVANIA

cppc

CIRCLE NO. 73 ON INQUIRY CARD